Morphology and Taxonomy of Late Cenozoic Uvigerine Foraminifera from Japan

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ABSTRACT

Japanese Miocene to Recent uvigerine foraminifera are studied taxonomically. For developing meaningful taxonomy, several morphological features are examined by means of optical and electron microscopes, and soft X-radiography: apertural apparatus including toothplate, coiling mode, wall structure, pores, ornaments, test size, prolocular size and length and breadth developments through ontogeny (growth pathway). Their biogeographic distributions are also inspected.

Two types of toothplates are recognized: euuvigerine and neouvigerine types. The euuvigerine toothplate is simple, straight, and attached to the lip of the preceding foramen. The neouvigerine toothplate is straight or trough-like, and attached to the outer margin of the preceding apertural neck. Three forms are discriminated among the neouvigrine type: a toothplate folded and concave to the side of the preceding foramen, a toothplate convex and folded away from the preceding foramen, and a straight one, each of which is represented by *N. setosa*, n. sp., *N. proboscidea*, and *N. interrupta*, respectively. The toothplate has stable characteristics, though its shape alters a little with the change of coiling mode through ontogeny. The adhesion patterns of the toothplate to the preceding foramen, however, are consistent, and do not change with coiling mode. Ontogenetic coiling alterations pose a practical problem with classifying juvenile individuals, though they provide a significant clue not only for morphological taxonomy but also for biological consideration.

The test wall consists of two morphologically different layers. A fibrous calcitic layer is covered with inner and outer veneers of granular nature. Through ontogeny, the wall thickens and surface configuration changes as the formation of the subsequent lamellae which are principally monolamellar.

The distribution of pores is more or less restricted. An imperforate area develops at the apertural apparatus including toothplates, and is closely related to the nature of veneers. The size and density of pores are changeable with environments, and similar among coexisting congeners. Therefore, pore patterns are a potential tool for the recognition of ecophenotypes rather than species.

Intraspecific variations in test size are mainly ascribed to those in chamber size. Uvigerine tests grow up by tri- to uniserial chamber adding. Among adult individuals the number of chambers is quite uniform within the same reproductive generation of a species. The frequency distribution of prolocular size is discrete, and bimodal within a given population — dimorphism corresponds to the number of chambers. Microspheric specimens have more chambers than in megalospheric ones. Test size, however, does not show any relation with prolocular dimorphism. Coexisting congeners are well assorted into clouds in their test size, probably implying resource partitioning.

The pattern of surface ornaments changes generally with water depth, though certain ornaments occupy different depth ranges in different bioprovinces. Shallow faunas are composed of a costate form which is replaced by a spinose-costate form with increasing water depth, and finally a spinose form occupies deep habitats.

From these morphological and biogeographical studies, 29 uvigerine morphotypes are distinguished: 19 come under *Euuvigerina* (*s.s.*), three *E.* (*Hopkinsina*) and seven *Neouvigerina*. They include eight new species or subspecies: *E. akitaensis grandis*, *E. akitaensis pumila*, *E. introrsa*, *E. kiyoshiasanoi*, *E. lobulata*, *E. nipponica*, *N. setosa*, and *N. takayanagii*.

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Key words: uvigerine foraminifera, Miocene to Recent, taxonomy, surface ornaments, toothplate, test wall, test size, pore, distribution

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INTRODUCTION

Uvigerine foraminifera are widespread, covering a wide range of environments, and constitute very important Cenozoic benthic formaminifera. Their morphology varies in space and along time succession. Biostratigraphers used this group as index-species in stratigraphic subdivision and correlation (Vella, 1961; Lamb, 1964; Hornibrook, 1968; Aoki, 1965). Their peculiar distributional patterns have been also used for paleoecological reconstructions (Streeter and Shackleton, 1979; Van der Zwaan, 1980; Ross and Kennett, 1984). Since d'Orbigny (1826) described *Uvigerina pygmea* from Pliocene sediments at Caroncina, near Siena, Italy, many uvigerine forms have been discovered and proposed as new species. However, the test morphology and ornamentation of some uvigerine foraminifera intergrade between several species, and their ontogenetic stages produce a series of characteristic surface configurations and forms. These features have led to a considerable confusion in taxonomy, and prevented a meaningful synthetic research for biostratigraphy and paleoecology.

Several morphological features have been proposed for uvigerinid classification at the generic level. Howe and Wallace (1932) separated their genus *Hopkinsina* from *Uvigerina* by its biserial coiling mode at the later stage. Hofker (1951) examined the internal structures of the family Uvigerinidae and proposed the types of toothplates as criteria of the generic classification. He mentioned that the toothplate is closely related to the coiling pattern of the test. His work was very novel and gave a potential tool for a systematic taxonomy because, until then, foraminiferal classifications had been mainly based on the external characters of the test. Vella (1961) essentially agreed to Hofker's philosophy and stated that the toothplate is an inadaptive character and proper for the generic separation. At the same time, he opined that internal structures are impractical for investigations of fossil specimens and that there is a fairly consistent relationship between the toothplate and external features such as sculpture (ornaments)

and test size. Hence, he proposed many new genera based on surface ornamentations. Loeblich and Tappan (1964) commented that surface ornamentations are of no practical use in executing generic separation, for which they adopted chamber arrangement, apertural position and its modifications, including toothplates.

The specific separation has been traditionally conducted on the basis of surface ornamentations, test form and size. Such characters, however, include a limited range of variations in uvigerine forms. This forces some taxonomists to define their species on the basis of a delicate difference of test morphology. On the other hand, some authors accept a wide range of variation on the ground that these morpho-parameters are easily changeable with environments.

Many studies (Bandy, 1960; Pflum and Frerichs, 1976; Van der Zwaan *et al.*, 1986) demonstrate that surface ornamentations of uvigerine forms change with increasing depth of habitat, and that intergradational types were found between distinct morphotypes (Van Leeuwen, 1986). It may be speculated that surface ornaments and test morphology have a homeomorphic characteristics which depend upon environments. Microstructure such as pores on the test surface was also considered in the specific classification (Lutze, 1986). However, it was documented by the investigation of planktonic foraminifera that pores are flexible with environmental changes (Wiles, 1967). Stapleton (1973) stated that recrystallization can produce extreme changes in ultrastructure, which is then not so useful in systematic studies of fossil specimens.

In such a situation, the present investigation attempted to clarify the general characters of uvigerine tests and relationships that exist among the morphologic characters, degrees to which certain morpho-parameters are stable, the kind of correspondence extant between test features and environments, and then to formulate a systematic classification of uvigerine foraminifera. For these purposes, the following characters were examined: wall structure, toothplate, apertural modifications, coiling modes, pores, surface ornamentations, prolocular size, test form, and size. Another aim of this study is to delineate the distribution pattern of uvigerine foraminifera in Japan. This study was made by employing Miocene to Recent materials from and around Japan.

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REVIEW OF PREVIOUS WORK ON JAPANESE UVIGERINIDS

Asano (1938) reported for the first time that many uvigerine forms, both fossil and Recent, are widely distributed in Japan, and that some species show distinct paleogeographic and biostratigraphic distributions. Later, he broadened our knowledge on the Japanese uvigerine foraminifera through the study of the Japanese Tertiary smaller foraminifera (Asano, 1950). Chiji (1959) observed *Uvigerina* to be an important genus in the biostratigraphy of the Japanese Neogene, and he reported that uvigerinid groups in the Toyama Tertiary basin changed their species compositions along with geological development. Matsunaga (1963) indicated that *Uvigerina subperegerina* Cushman and Todd is a diagnostic species in the oil fields of northern Japan, and he applied this species with associated ones for comparison between fairly spaced districts. Aoki (1965) studied Pliocene and Pleistocene uvigerinid foraminifera from the Boso and Miura Peninsulas, and demonstrated their characteristic distributions vertically and horizontally. He also mentioned that these peculiar distributions are closely related to ecologic conditions, and so, if any separated areas were under different environments, it is very difficult to use uvigerinid species as a guide to stratigraphic correlation. Many other workers reported fossil uvigerinids from several Japanese Neogene sequences (Ishiwada, 1950; Ishiwada *et al.*, 1962; Kikuchi, 1964; LeRoy, 1964; Matoba, 1967; Kitazato, 1977, 1979; Hasegawa, 1979; Sharma and Takayanagi, 1980; Nomura, 1986). They successfully used uvigerinids in regional biostratigraphic zonation and the reconstruction of paleoenvironments. Recent studies have shown that modern uvigerinids show a peculiar depth distribution around Japan (Ishiwada, 1950; Asano, 1958; Ikeya, 1971; Matoba, 1976, 1984; Kaiho and Hasegawa, 1986; Ōki, 1986). At the same time, it was also pointed out that the depth range of each species varies among biogeographical provinces, like as other foraminifera (Kitazato, 1979; Matoba, 1984).

MATERIALS

Neogene marine sequences occur widely in Japan and commonly contain planktonic and benthic foraminifera, where uvigerine forms are occasionally diagnostic. Eight provinces were selected for investigation of the paleogeographic and stratigraphic distributions of fossil forms (Fig. 1). These land sections cover the geologic interval from Early Miocene to Pleistocene. The geologic settings and age assignments of each province treated in this paper are quotable from the following articles: Miyakojima (Nakagawa *et al.*, 1977; Nakamori*, 1982), Okinawa (Natori, 1976; Ujiié, 1985), Miyazaki (Suzuki*, 1987), Boso Peninsula (Mitsunashi, Yasukuni and Shinada, 1959; Oda, 1977; Mitsunashi *et al.*, 1979), Himi (Hasegawa*, 1979; Hasegawa and

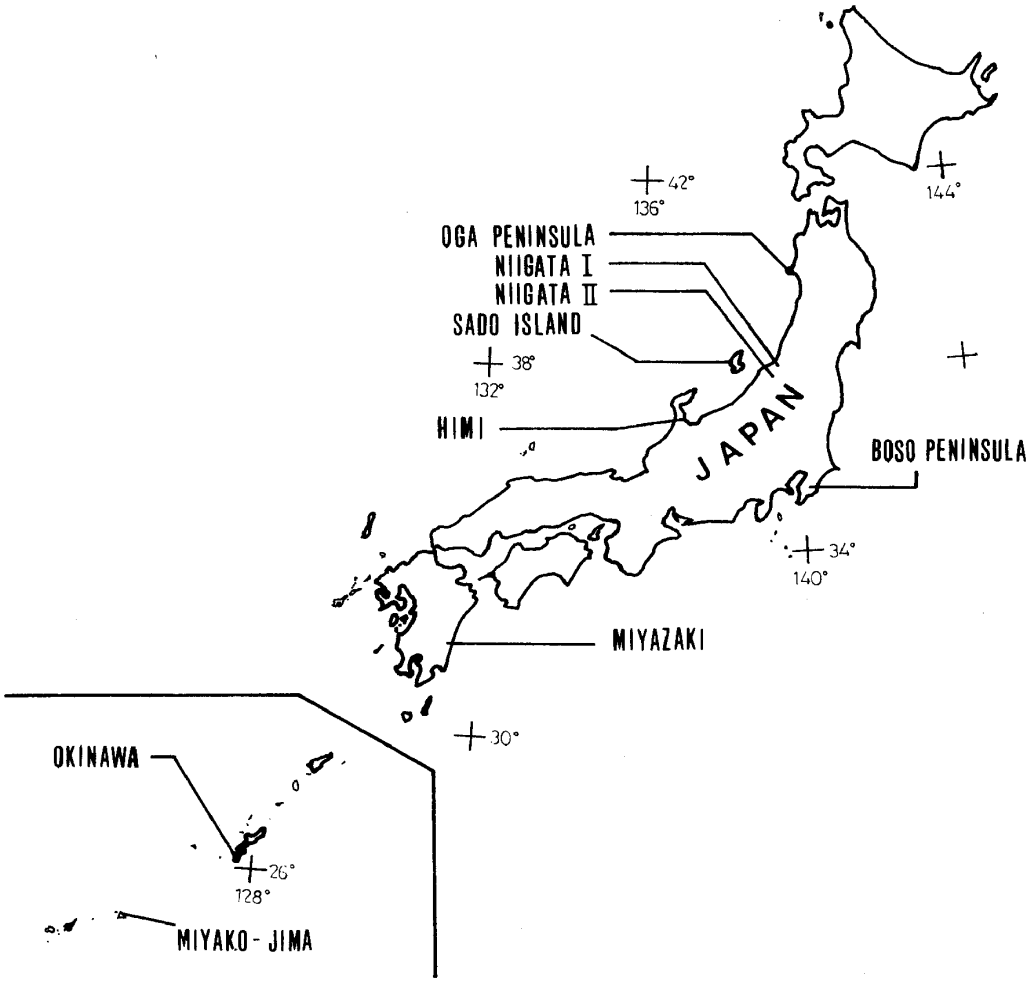


Fig. 1. Map of the Japanese Islands showing onshore sample location.

Kobayashi, 1986), Sado Island (Utashiro *et al.*, 1977), Niigata I (Shimazu *et al.*, 1986; Komatsubara*, 1986MS), Niigata II (Maiya, 1978) and Oga Peninsula (Kitazato, 1975; Jung, 1985MS). Asterisked authors provided useful samples for this study.

Recent specimens were obtained from the Japan Sea and northwestern Pacific Ocean off Japan (Fig. 2). The northwestern Pacific can be divided into three provinces on the basis of the property of water masses and hydrography: Oyashio area with cold surface currents, Kuroshio area with warm currents, and mixed zone of both, or Transition area (Kawai, 1972). Sample stations or traverses 1–5 are situated in the Kuroshio area, 6–8 in the Transition area and 9 in the Oyashio area. The Japan Sea develops a peculiar water mass called the Japan Sea Proper Water below 200-m water depth (Hidaka, 1966). This water mass is vertically uniform and characterized by low temperatures (less than 1°C) and high dissolved oxygen content (above 5 ml/l), respectively (Matoba, 1984). All the examined samples were taken under this peculiar water mass except for St. 15.

INTERNAL MORPHOLOGY AND WALL STRUCTURE

In this chapter, toothplate developments, andoanulus, wall microstructure,

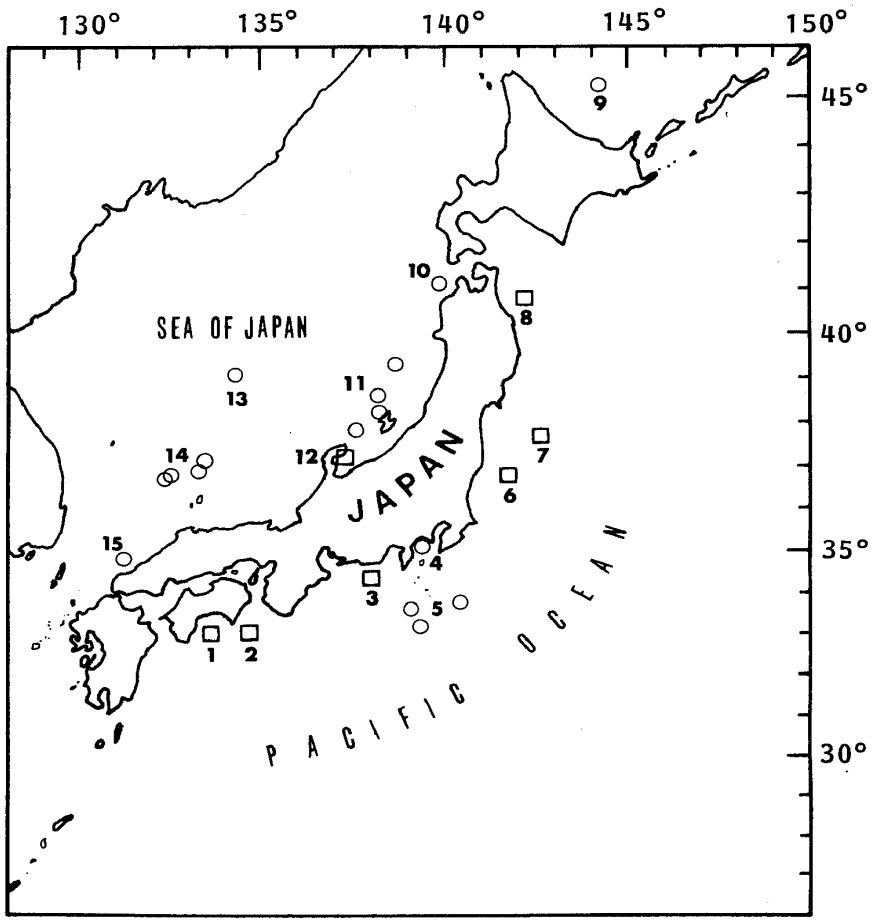


Fig. 2. Location of sea bottom samples around the Japanese Islands.
1. Tosa Bay, 2. Kii-suido, 3. Enshu-nada, 4. Sagami Bay, 5. off Hachijo Island, 6. off Onahama, 7. off Sendai, 8. off Hachinohe, 9. Okhotsk Sea, 10. off Nishitsugaru, 11. off Sado Island, 12. Toyama Bay, 13. Yamato Bank, 14. off Oki Island, 15. off Shimonoseki. Square: traverses; circle: spot samples.

lamellar wall construction and perforation are discussed. For observation of internal structures, many specimens were sectioned by employing the Canada balsam-Xylene method introduced by Nomura (1983a, b). For investigations of wall microstructures, etching was made by using a 2.5 percent solution of glutaraldehyde buffered by 0.5 mol phosphate. The etching time was varied according to wall thickness or desired points from 4 to 15 sec. The method was also described in detail by Nomura (1983b). All observations were performed by using a JEOL JSM-25SII scanning electron microscope.

1. Toothplate

Hofker (1951) examined toothplates of the family Uvigerinidae Haeckel and recognized five groups at the generic level by oral characteristics; *Praeuvigerina*, *Angulogerina*, *Euuvigerina*, *Aluvigerina* and *Neouvigerina*. After his work, the toothplate has been the very point under discussion respecting the classification and functional morphology, together with other skeletal characters. The family Uvigerinidae can be divided into two subfamilies: Uvigerininae with rounded and inflated chambers, and Anglogerininae with triangular test form (Loeblich and Tappan, 1984). Here, the Japanese

Miocene to Recent subfamily Uvigerininae Haeckel are illustrated and discussed from the viewpoint of toothplate. On the basis of their toothplate types, all the Japanese Uvigerininae can be classified into two major groups, euuvigerine type and neouvigerine type, but no aluvigerine type was detected in Japan.

1-1. Euuvigerine type

A schematic toothplate of *Euuvigerina* Thalmann is illustrated in Fig. 3, and SEM photographs of toothplates for various euuvigerine species are given in plates (Pls. 27-31). Eleven species and one subspecies sectioned are *E. akitaensis* (Asano), *E. akitaensis grandis*, n. subsp., *E. flintii* (Cushman), *E. hispida* (Schwager), *E. introrsa*, n. sp., *E. juncea* (Cushman and Todd), *E. lobulata*, n. sp., *E. nipponica*, n. sp., *E. kiyoshiasanoi*, n. sp., *E. shiwoensis* (Asano), *E.* (*Hopkinsina*) *shinboi* (Matsunaga) and *E.* (*Hopkinsina*) *wakimotoensis* (Asano).

The euuvigerine type has a simple plate-like toothplate. It is attached to the lip of the preceding aperture at the base and runs up into the apertural neck, attaching itself to the inner side of the neck on one of the narrow side, but keeping the other side to be free. In rare cases, an abnormally developed toothplate divides the surface of the preceding aperture into two, placing its base across the preceding one (Pl. 31, fig. 2).

The pattern of toothplate is fairly in accordance with the inner shape of chamber (Pl. 27, fig. 3). Usually the toothplate initiates on the lip of the preceding aperture and runs straight up, and then it folds the free part into the apertural channel at an angle of approximately 120 degrees. A portion where the toothpate begins to fold is near the andoanulus (cf. Knight, 1986). If toothplate does not develop the folding part, its broad plane will adhere to the inner side of an apertural neck. The

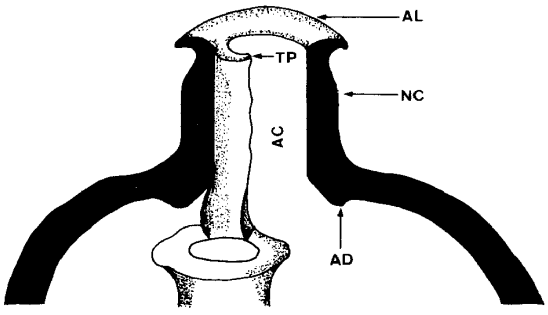


Fig. 3. Schematic cross-section showing apertural apparatus of *Euuvigerina*. AL: apertural lip; NC: neck; TP: toothplate; AC: apertural channel; AD: andoanulus.

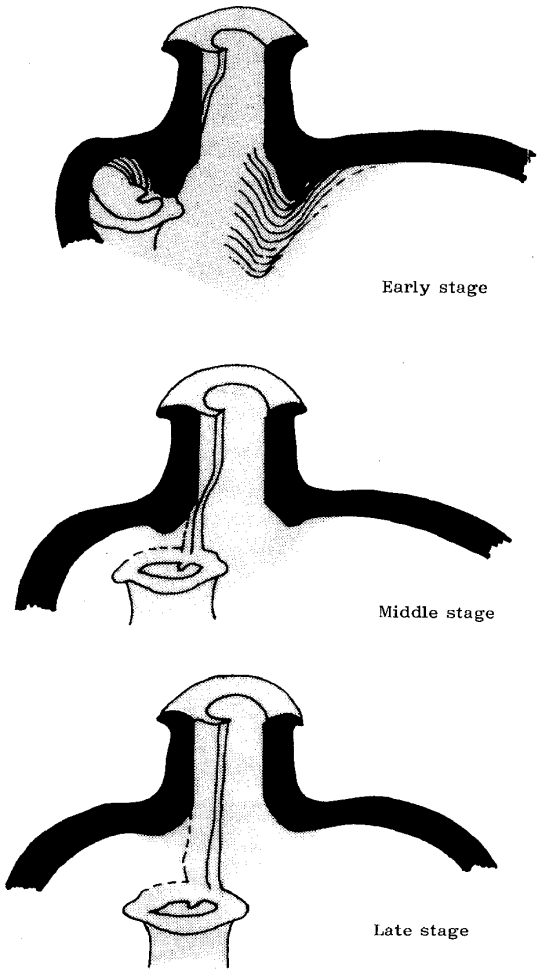


Fig. 4. Schematic cross-sections of *E. akitaensis grandis*, showing toothplate development through ontogeny. Dotted area indicates imperforate surface.

development of its folding is closely related to the coiling pattern of tests. Euuvigerine tests grow up by adding chambers triserially, which lead to toothplate folding.

The subgenus *Hopkinsina* Howe and Wallace changes test coiling from the triserial in the early stage to bi- to uniserial later on. Some species of *Euuvigerina* (s.s.) also have the last-formed one or two chambers which are coiled biserially and/or uniserially. Thus, the degree of folding is changeable through ontogeny. The ontogenetic changes in the pattern of chamber formation also lead to the positional alteration of a toothplate. Figure 4 expresses the ontogenetic development of a toothplate in *E. akitaensis grandis*. In a juvenile stage, the toothplate is not connected with the preceding chamber, instead the vertical hem of prominently developed andoanulus lies on the apertural lip of the preceding. The toothplate appears from the lower portion of the neck and broadens toward the apertural end. In the middle stage, the toothplate starts on the apertural lip of the former and folds near the slightly deflated andoanulus. In the final chamber added biserially, the toothplate is based on the preceding apertural lip and runs up into the apertural neck without any distinct folding.

The thickness of the toothplate varies among species. *E. flintii* has the thickest toothplate among the examined species, being 12.5 μm thick. On the other hand, *E. akitaensis grandis* and *E. juncea* have much thinner toothplates with 7.5 μm and 4.5 μm thickness, respectively. The surface of the toothplate is imperforate and smooth.

1-2. Neouvigerine type

Neouvigerina Thalmann develops various kinds of toothplates, but it is easily differentiated from the euuvigerine type by the pattern of toothplate attachment to the preceding aperture. The toothplate of the neouvigerine type is attached to the outer side of the apertural neck or the outer border of the lip of the preceding chamber.

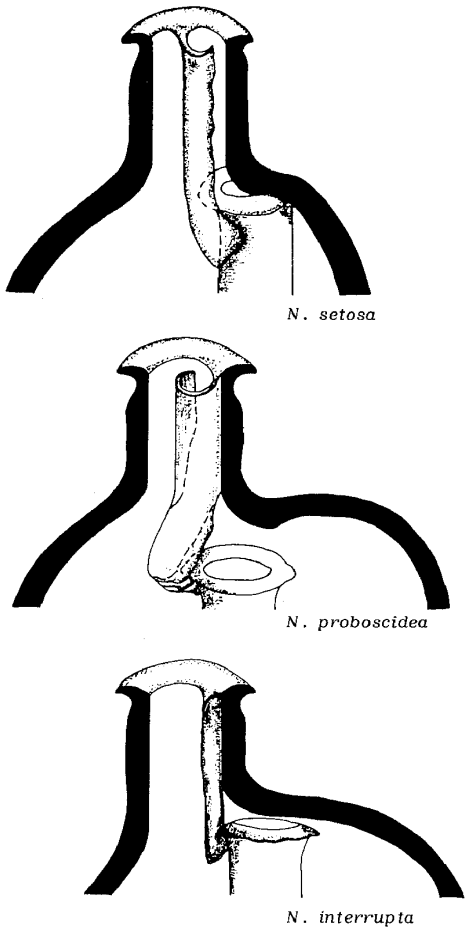


Fig. 5. Schematic cross-sections of three species of *Neouvigerina*, showing toothplate formation.

Figure 5 shows three types of toothplates in *Neouvigerina*. These drawings are based on the SEM photographs of *N. setosa* n. sp., *N. proboscidea* (Schwager) and *N. interrupta* (Brady). The toothplate of *N. setosa* is tightly adhered to the neck of the preceding aperture at its shovel-shaped base and runs straight up into the apertural neck, attaching itself to the inner side of the neck and the uppermost part of chamber on one of the narrow sides, but keeping the other side

to be free. The toothplate is folded and concave to the side of the preceding aperture, and then the trough of the toothplate is harmoniously connected to the preceding aperture. The greater part of the preceding aperture is, however, covered up by the succeeding chamber as added (Pl. 32, figs. 1, 3, 6).

The toothplate of *N. proboscidea* shows a more or less different pattern from *N. setosa*. The free part of the toothplate is strongly folded away from the preceding aperture and the lower convex part adheres to the apertural neck of the preceding one. The toothplate is also attached to the inner side of the neck and chamber on one of the narrow sides (Pl. 32, figs. 4, 5, 7).

The toothplate of *N. auberiana ampullacea* (Brady) is also folded along the longitudinal axis, attaching to the inner side of the neck and chamber on a narrow side, and connected with the apertural neck or occasionally the outer border of the preceding lip at the base (Pl. 32, figs. 2, 8, 9).

Those toothplates shaped into a trough are quite different from the Hofker's illustrations for neouvigerine forms which show simple plate-like toothplates (Hofker, 1951, Figs. 117, 118). This plate-like toothplate is detected in *N. interrupta*. The toothplate in this form is very fragile, and is attached to the inner side of the apertural neck and chamber at its one side. The lower portion of the toothplate is tangentially adhered to the preceding apertural neck. On the contrary, in the Hofker's sketch, the lower part of toothplate of *N. interrupta* is streched out from the preceding neck at right angles to the surface.

The thickness of neouvigerine toothplates is approximately 3 μm in average, being much thinner as compared with that of euuvigerine one. The surface of the toothplate is smooth and imperforate.

2. Mechanism of Toothplate Formation

Hofker (1951) stated that a toothplate is built up first, and the chamber wall is afterward formed around it. It may be reasonable to assume that toothplates are constructed at the terminal stage of chamber formation. A concordant relationship between test coiling and the ontogenetic development of toothplates is ascribed to subordinate relations of toothplates to chamber formation. Comparing toothplates between the uniserial portions of *Euuvigerina* and *Neouvigerina*, it is easily recognized that toothplates of each genus are characterized by the pattern of attachment to the preceding apertures. Ontogenetic variations of toothplates are not over the generic characters.

Three patterns of toothplate formation in the Uvigerininae are recognized in an examination on the cross-sections (Fig. 6). The first is a simple plate-like

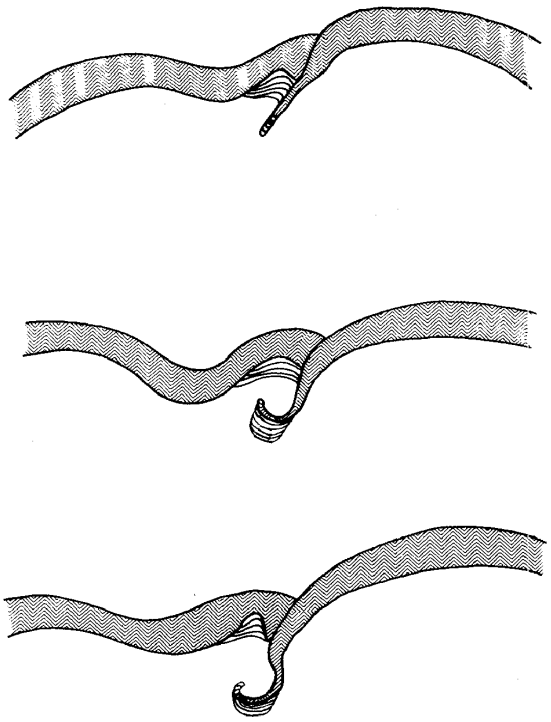


Fig. 6. Schematic illustrations showing toothplate development in uvigerine foraminifera.

projection, and the second is a trough-like projection. The third is also shaped like a trough but the trough is progressively twisted along the length of the projection. All these projections resulted from the collision of the chamber walls on the two marginal sides. One side of the chamber wall is strongly bent inwards and forms a toothplate. The other side is confronted by the folded face of another and strained to a slight fold. Then, toothplates are no more than the folded part of the test wall. SEM micrographs support this interpretation as to the formation of toothplates (Pl. 27, fig. 6; Pl. 28, fig. 8; Pl. 32, fig. 5). This phenomenon agrees well with Höeglund's metaphor for the toothplate of uvigerinids (1947). He compared a chamber to the double-breasted mantle and a toothplate to the folded part of the inner breast.

The portion of this collision appears to be a depressed line along the longitudinal axis on the outer side of a chamber and situated on the anterior portion of a chamber, or the side near the coiling axis, where chamber is the shortest in length. The word "anterior portion" is here used in the sense of Höeglund (1947).

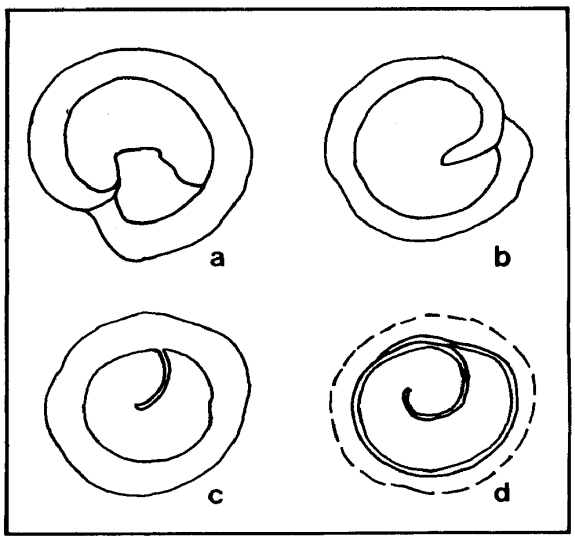


Fig. 7. Apertural views of toothplates of *E. akitaensis* (a), *E. juncea* (b), *N. proboscidea* (c) and *N. setosa* (d).

Figure 7 shows apertural views of toothplates for four selected species: *E. akitaensis*, *E. juncea*, *N. proboscidea* and *N. setosa*. It is also recognized in a specimen with an apertural lip lacking its uppermost part (Fig. 7d) that the toothplate is continued to the test wall. This continuity also implies that the toothplate is composed of the same sheet as the test wall. The veneer, developed at the apertural part, cements and seals the seam of the both chamber walls (Fig. 7c).

3. Andoanulus (Pls. 27–32)

A projection is developed on the inner side of the apertural base. Figure 4 shows the ontogenetic development of the projection in *E. akitaensis grandis*. At the juvenile stage, this projection formed just below the inner apertural base faces the anterior portion of a chamber, and assumes a "V" shaped trough opened to the apertual side. It is strongly protruded, and stretched up to the apertural lip of the preceding chamber. During the ontogenetic development it is gradually shrunk and its shape changes from a "V" shaped trough to an inflated ring along the inner side of the apertural base.

The term "andoanulus" was introduced by Knight (1986) for the apertural apparatus of *Oolina* d'Orbigny. Here, this term is adopted for the above mentioned projecting part. Though greatly different at the early stage from that of *Oolina wiliamsoni* (Alcock), its shape in the later stage is very similar to that of andoanulus Knight described, as a ring along the inner apertural base is slightly protruded into the cavity of the chamber.

The andoanulus of the Uvigerininae is imperforate and smooth. In the present study some specimens of *E. juncea* are formed more or less perforated in their andoanuluses, but these features are due

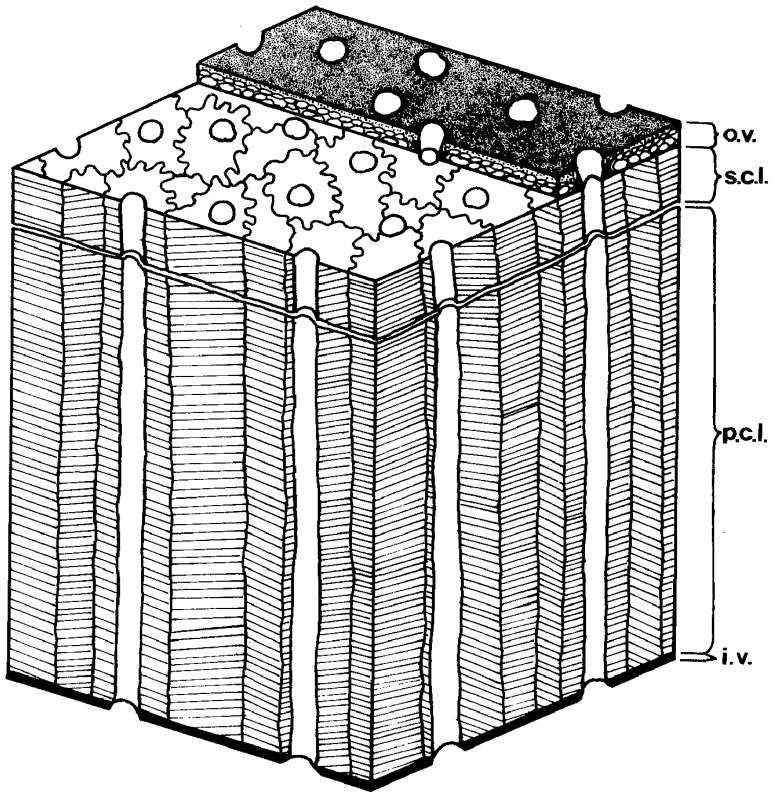


Fig. 8. Block diagram of wall structure in *Euuvigerina*. o.v.: outer veneer; i.v.: inner veneer; p.c.l.: primary calcitic lamella; s.c.l.: secondary calcitic lamella.

to natural dissolution of the inner veneer (Pl. 27, fig. 5).

4. Wall Ultrastructure

Figure 8 shows a schematic block diagram of wall structure in *Euuvigerina* Thalmann. The test wall of euuvigerine foraminifera can be divided into four layers: the primary and secodary calcitic lamellae and the inner and outer veneers. Those calcitic lamellae are composed of numerous crystal elements which show a definite preferred orientation perpendicular to the test surface and are tied up in a several bundles, or crystal units (Pl. 26, figs. 3–6). On a naturally etched wall surface, the boundaries of crystal units are distinct and appear to be a jig-saw puzzle (Pl. 33, figs. 3, 4, 11). The columns of crystal units are occasionally composed of a fine structure that appears as piles of minute plates (Pl. 26, figs. 2, 5). Towe and Cifelli attributed this fine stucture to a cleavage and growth increments (1967, Pl. 91, fig 3; Pl. 92, fig. 2). The boundary of the primary and secondary calcitic lamellae has probably been developed by the temporary pausing of calcification, and appears to be a crack line in some specimens. This set of calcitic lamellae is covered with the inner and outer veneers (Pl. 27, figs. 1, 2).

These veneers are composed of granular calcite instead of fibrous calcite. Figure 9 shows the successive development of an outer veneer. The calcite grains gradually decrease in size toward the outer surface. The outer veneer is smooth on the very surface (Pl. 33, fig. 8) and has a sutured appearance like an amoeboid mosaic in the middle part, but the pore margins are still smooth (Pl. 33, fig. 1). Similar phenomena in this middle part were recognized in the granular layers of *Ammonia beccarii*

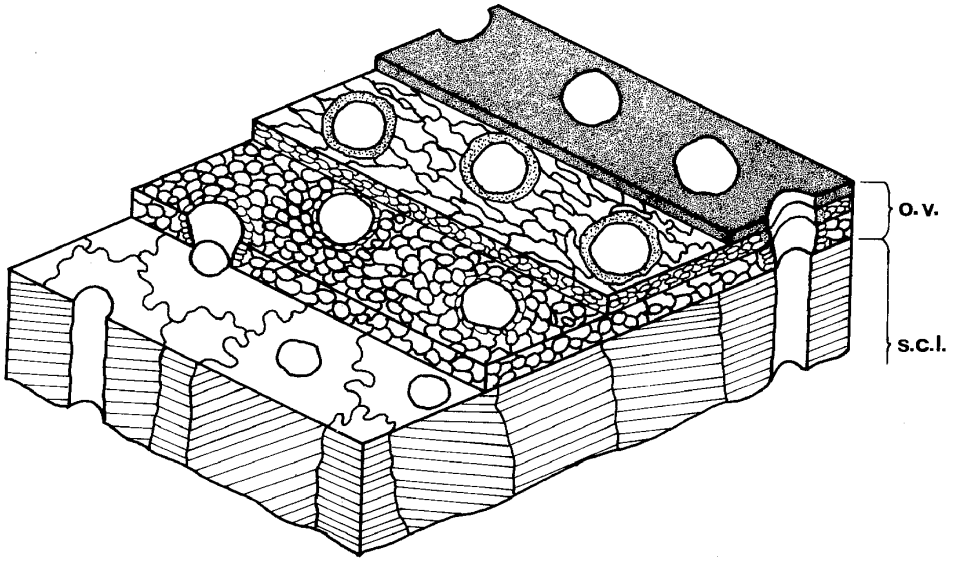
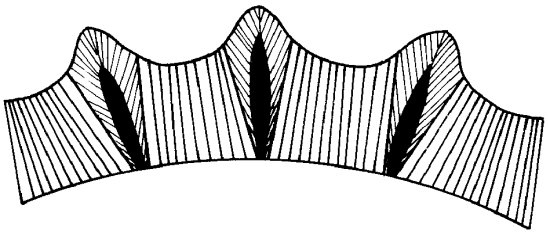
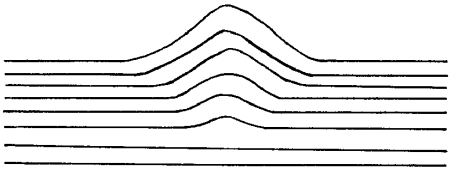


Fig. 9. Block diagram of upper part of test wall, showing details of veneer development. o.v. : outer veneer ; s.c.l. : secondary calcitic lamella.

(Linné), *Chilostomella ovoidea* (Reuss) (Towe and Cifelli, 1967, Pl. 91, fig. 1 ; Pl. 96, fig. 3) and *Globorotalia truncatulinoides* (d'Orbigny) (Takayanagi, Niitsuma and Sakai, 1967, Pl. 9, fig. 2). Though *A. beccarii* is optically radial, its veneer is morphologically of granular nature (Banner and Williams, 1973).



a. Textural



b. Inflational

Fig. 10. Two types of costa development in uvigerine tests.

The inner surface of the outer veneer in contact with the fibrous calcite layer is of completely granular nature, where grains around pores are more compactly aggregated than those in inter-pore areas. A similar mode of development is also observed on an inner veneer.

Figure 10 diagrammatically illustrates the development of textural and inflational costae. The wall structure of textural costae is greatly different from that of non-costate parts. Its crystal elements are branched from the imperforate costal stem at an acute angle and appear to be chevrons (Pl. 26, figs. 1, 2). The costa developed in the initial portion shows an inflational nature. This inflation is formed by the process of lamellar construction of posterior chambers.

Pores penetrate the chamber wall, and are generally located within crystal units, but they are open along the boundaries of crystal units in rare cases. This distribution pattern of pores resembles that of *Bulimina marginata* d'Orbigny (Hansen, 1970, Pl. 17, fig. 2), but is quite different from those observed in the family Cassidulinidae. Nomura

(1983b) observed that constricted pores are usually open at the sutured boundaries in genera forming fibrous crystalline structures.

The size of crystal units varies among species. For example, the crystal units of *E. akitaensis* (Asano) range from 3 to 5 μm in width and those to *E. juncea* (Cushman and Todd) from 2.0 to 2.5 μm. The thickness of crystal elements is from 0.16 to 0.20 μm in *E. akitaensis*.

5. Lamellar Wall Construction

Problems concerning lamellar characters in foraminifera have been the cause of much heated discussion and many pages of print. This is related to the fact that the pattern of lamellar construction is one of the important keys in the foraminiferal classification of some taxonomists and in understanding of the processes of chamber formation. However, there are many discordant views on lamellar construction. Such a contradiction sometimes results from

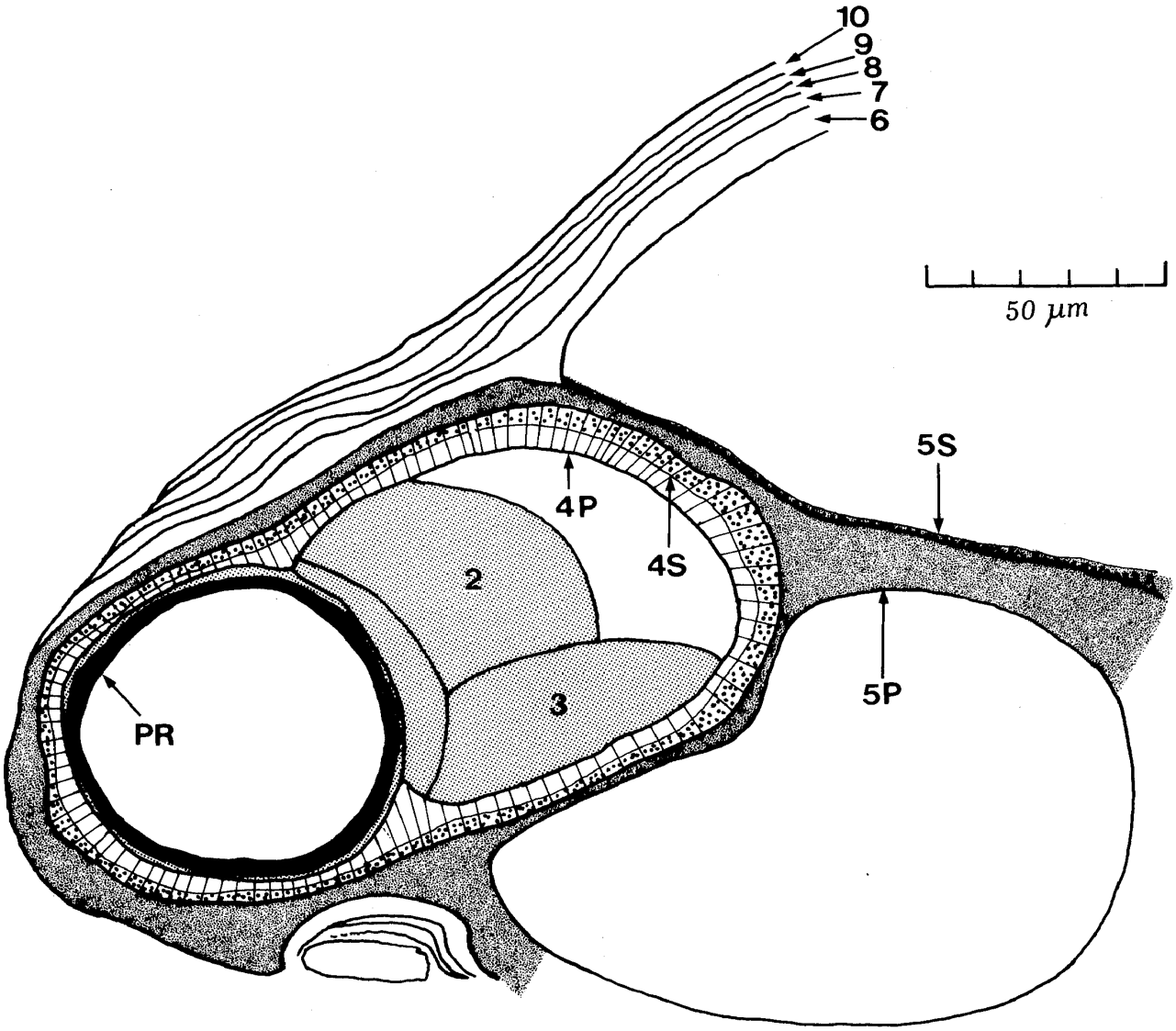


Fig. 11. Lamellar construction in *E. akitaensis* (Illustration based on Pl. 25, fig. 3). PR: proloculus; numeral: lamella of 'i'th chamber; P: primary calcitic lamella; S: secondary calcitic lamella.

different concepts of lamellar characters among researchers. The Uvigerinidae has been regarded to develop a monolamellar test wall (Reiss, 1958, 1963; Loeblich and Tappan, 1964). Later, Haynes (1981) interpreted his Buliminida including the Uvigerinidae as strictly bilamellar forms with a surface veneer. The veneer, however, has a character quite different from the typical outer lamella of bilamellar forms, and is continuous from the calcitic layer below. Any canal-system of Reiss (1957) can not be detected between the veneer and the calcitic layer. Hansen and Reiss (1972) mentioned that the bilamellar structure is a general feature of all perforate and lamellar foraminifera. On the other hand, Hofker (1971) stated that the globigerine group is primarily monolamellar. This monolamellar construction in rotaliid forms has also been observed by Sliter (1972) and Nomura (1983b). It is also reported that lamellar charaters are variable among species (Towe, 1971; Conger, Green and Lipps, 1977).

Figure 11 shows the lamellar pattern of early chambers including a proloculus in *Euuvigerina akitaensis* (Pl. 25, fig. 3). The 2nd chamber with a non-lamellar character is simply added. Lamellar construction begins at the episode of the 3rd chamber formation. During the episodes of the 3rd to 5th chamber formation, the lamella of each new chamber overlaps the whole exterior of the earlier formed ones with a monolamellar character. The 3rd chamber is composed of a single lamella, which constructs the typical monolamellar character. At the time of the 4th chamber formation, two distinct lamellae are developed. The primary (inner) lamella is not restricted to its chamber but extends over to cover the earlier chambers in the same way with the secondary (outer) lamella. Therefore, these two lamellae do not correspond to the inner lining and outer lamella of Reiss (1957) in bilamellar forms. At the 5th chamber formation, the thick primary lamella develops a monolamellar character, but the secondary one is not traceable under the lamella of the 6th chamber and is only visible at the septal face. If this lamella is formed during the episode of the 6th chamber formation, it is correlated with the septal flap of rotaliid forms. Considering its thickness and the pattern of adhesion to the lamella below, it appears, however, that this lamella is formed during the episode of the 5th chamber formation and only be the secondary lamella. It is noteworthy that the primary lamella of the 5th chamber also calcifies on the septal face where three lamellae are observed. It continues on a single lamella which covers earlier chambers. After the 6th chamber formation, lamellae of newly added chambers cover the earlier parts of the test, but the thickness of each lamella gradually decreases and is pinched out toward the early portion of the test. The final chamber is composed of a single lamella which does not cover earlier chambers including the penultimate chamber just as non-lamellar construction of the 2nd chamber (Pl. 25, fig. 2). Figure 12 systematically illustrates the ontogenetic development of lamellar characters based on the above observations.

E. hispida shows a more or less different lamellar construction as compared with *E. akitaensis*. Broken spines of the penultimate chamber are

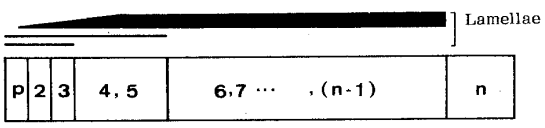


Fig. 12. A model of lamellar construction in *E. akitaensis* through ontogeny.
p: proloculus; numeral: 'i'th chamber; n: final chamber.

covered with two additional lamellae (Pl. 47, fig. 9). This lamellar character implies that the final chamber is composed of two distinct lamellae; the primary and secondary ones which both cover earlier chambers.

Although the Uvigerinidae essentially develops monolamellar characters, the pattern of its lamellar character is more or less variable during ontogeny and among species. This lamellar character produces a series of characteristic surface configurations and morphology during ontogeny. For example, the proloculus does not develop any ornaments, but its outside is usually ornamented with costae and others. These costae are developed from the lamella inflation of posterior chambers (Fig. 10b).

6. Perforation

The inner and outer surfaces of the main parts of chambers are perforated, though the distribution of pores in the Uvigerininae is more or less restricted. Imperforate areas are developed on the inner and outer surfaces of apertural necks, toothplates, andoanulus and its marginal parts, spine and true or textural costae. Sections of these imperforate portions demonstrate, however, that, except for spines, their fibrous calcitic layers have definite pore tubules similar to those forming perforate surfaces (Pl. 27, figs. 1, 2).

Imperforate portions on the inner surface of the test is actively formed by the development of an imperforate inner veneer. The outer surfaces of textural costae and apertural necks are thickened by a more strongly developed outer veneer as compared with a perforate surface. Therefore the imperforate portions on the outer surface are simply owing to the discriminative calcification of veneers. This preferential calcification may be ascribed to the sterility of pore tubules because their pore tubules can not communicate with protoplasm

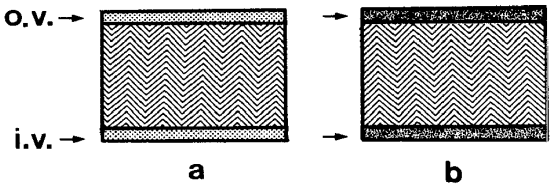


Fig. 13. Schematic wall sections of chamber part (a) and apertural neck (b), showing incoherent veneers which are perforate in chamber part and imperforate at apertural neck.

within the test due to the imperforate inner veneer in the neck and their branching from the imperforate stems in costae. Concurrently, the imperforate nature of the outer surfaces of textural costae and apertural necks is passive. Spines have a distinct wall texture and are imperforate throughout their sections.

Figure 13 shows incoherent veneer development between the perforate surfaces and the imperforate apertural neck. Hofker (1951) mentioned that the apertural neck of the Cretaceous Uvigerinidae is provided with pores and that of the Tertiary Uvigerininae (Uvigerinae, as it was called) is not perforated. These evolutional changes may be closely related to veneer development. It is implied that the Cretaceous Uvigerinidae develops cognate veneers in both the chamber part and the apertural part, and then the apertural neck is also perforated. The Tertiary Uvigerininae forms, however, heterogeneous veneers between the mentioned parts, which leave perforations on the surface of chambers and cover pores of the perforated calcitic layer in the apertural part. The veneers can be removed by post-mortem dissolution, and then the apertural necks of some Tertiary specimens come to show perforated surfaces through fossilization (Pl. 32, fig. 7).

Pore tubules shut off from the deposition of outer veneer are open on the test surface. These pore tubules run

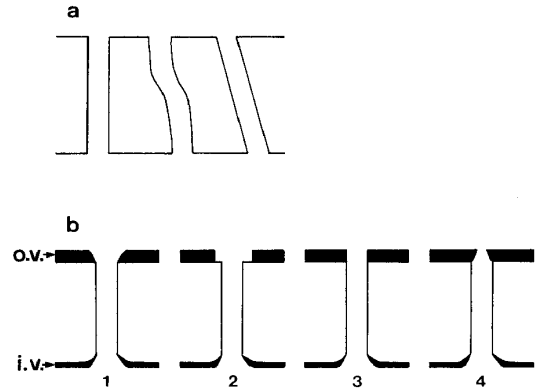


Fig. 14. Three types of pore penetrations (a) and modification of surface openings made by veneers (b).
o.v.: outer veneer; i.v.: inner veneer.

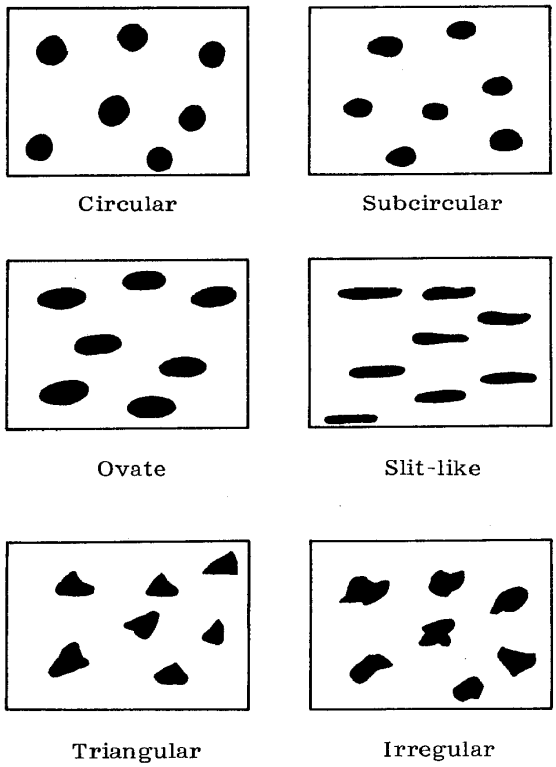


Fig. 15. Six types of pores on external test surface.

parallel to the crystal elements and are usually perpendicular to the surface, though they occasionally get bent by lamellar construction and are off center near textural costae (Fig. 14a). Pore tubules are principally cylindrical in shape, but are beveled on the inner and/or outer surfaces of the test. Figure 14b illustrates four types of beveling. The pattern of beveling is constant on the inner surface, but is variable on the outer surface according to the developmental pattern of outer veneers. Subsequently it is suggested that the veneer greatly influences the size and shape of pores. Lynts and Pfister (1967, Fig. 15) illustrated two types of beveling, although they did not note the cause of beveling.

The shape and size of pores and their number per areal unit change through ontogeny and are also variable among specimens of a single species. The pattern of pores has been believed as a consistent character at the specific level and used in classification (Hofker, 1951; Lutze, 1986). Though some species show pores of peculiar character which depends mainly upon their environments. These problems are discussed in detail in the chapter of "Shell Porosity".

Figure 15 illustrates diagrammatically various shapes of pores of the Uvigerininae, ranging from circular to slit-like (Pl. 33). Some specimens show such triangular or irregular pores, which have been altered after fossilizations. As mentioned above, the pattern of pores is controlled by the veneer, whose relief is concurrently closely related to the distribution of pores. The veneer possessing domes occasionally occur near sutural depressions of *Euuvigerina shiwoensis* (Asano) (Pl. 33, fig. 5). Domes are only developed in marginal portions around pores to elevate pore margins above the surface and open at the crest of a dome whereas in the part of chambers they have slightly inflated rims (Pl. 44, fig. 5). Similar phenomena are reported in *Bolivinita* by Scott (1978). He mentioned that domes are progressively formed by local calcification around pores. It seems, however, that domes represent more thickly calcified parts of the normal veneer. These domes are also found on the intercostal trough of *E. akitaensis*

(Asano) (Pl. 33, fig. 12). The etched surface demonstrates that pore tubules increase its length in correspondence with dome formation. Though *E. akitaensis* usually develops featureless, circular to subcircular pores, the morphotype having elevated pores occurs in a certain sample most abundantly. Test morphology of this morphotype is, however, the same as that of forms showing featureless pores. The relationships between the veneer and pores indicate that active pores are never covered in the processes of veneer formation and are functional in any role.

The function of pores has been mentioned variously by several authors — for example, osmotic (Le Calvez, 1947); osmotic or excretory, or providing organic continuity to the test exterior (Sliter, 1974); excretory (Anderson and Bé, 1976); osmoregulation, gas exchange or intake and excretion of dissolved organic substances (Berthold, 1976). Berthold (op. cit.) commented that the pore function is essential to the organism, particularly in a reproductive phase. Coleman (1980) stated from the study of the agglutinated foraminifer *Clavulina* that the pores may be functional only during the periord of chamber construction and toothplate development. If the pore tubule is a passage from the interior to exterior of the test, it should persist through the subsequently deposited lamellae. Though the well-developed canaliculi of Reiss (1963) is not found in this investigation, the sectioned wall shows traces of pore tubules, which continue from the innermost lamella to at least the succeeding lamella (Pl. 25, fig. 1). Hence, the

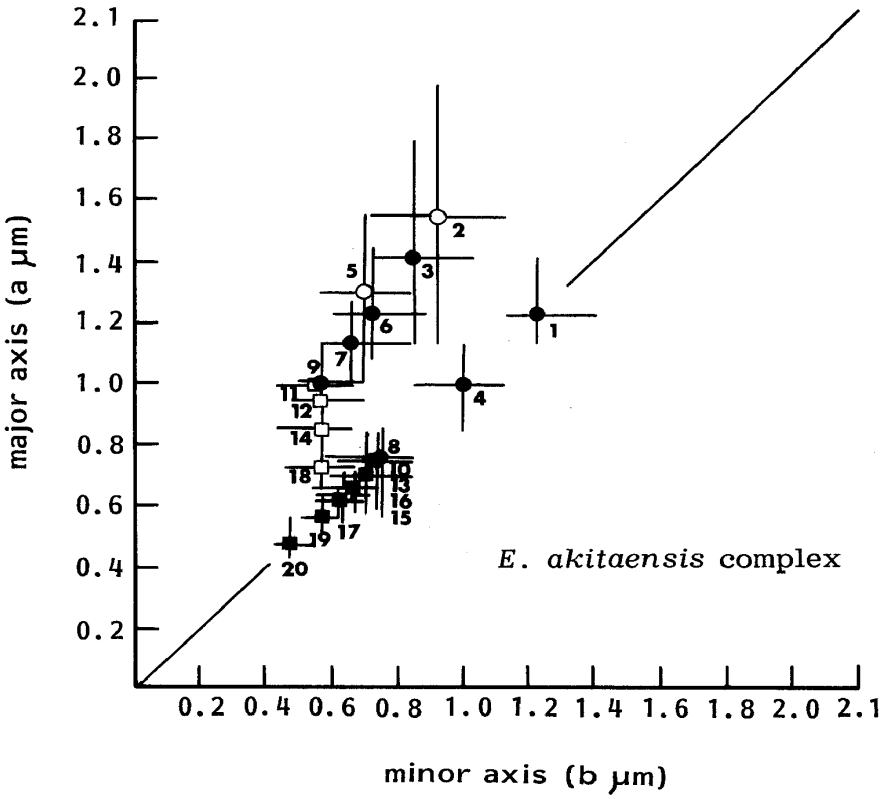


Fig. 16. Mean pore size distributions for twenty specimens of *E. akitaensis* complex. 3, 6, 9: subsp. *grandis*; 10, 20: subsp. *pumila*; the others: typical form. Circle: from Japan Sea and adjacent onshore sections; square: from N.W. Pacific and neighboring onshore sections. Solid: fossil; open: Recent. Crossed bars: observed ranges of pore size.

final and penultimate chambers may be possible to communicate with the exterior through pore tubules. Usually pores in the earlier portion are strongly deformed as compared with those in the later. The degree of deformation seems to be related to aging and missing function of pore tubules of the lowest lamella.

SHELL POROSITY

The number, size and shape of pores were regarded as stable characters within a species, and then used for classification at the specific level by some authors (Hofker, 1951; Lutze, 1986). On the other hand, it is also documented from investigations of planktonic foraminiferal species that the characters of pores are relatively uniform among coexisting species and are variable with changing environment or temperature (Wiles, 1967; Bé, 1968; Frerichs *et al.*, 1972). The present study is focused on clarifying whether pores have a unique charater within a species or are changeable with environments where individuals live.

In this investigation, the scanning electron microscope was used for count-

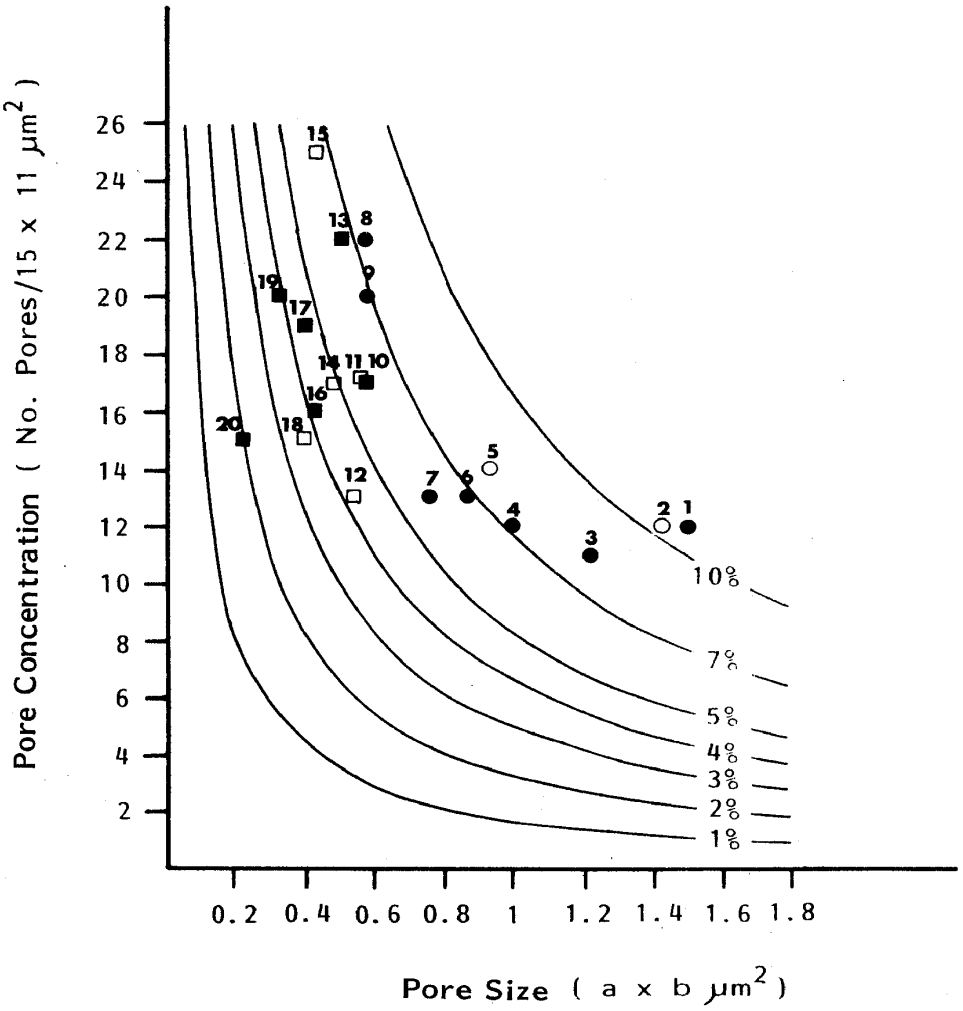


Fig. 17. Shell porosity of *E. akitaensis* complex. Legend same as in Fig. 16.

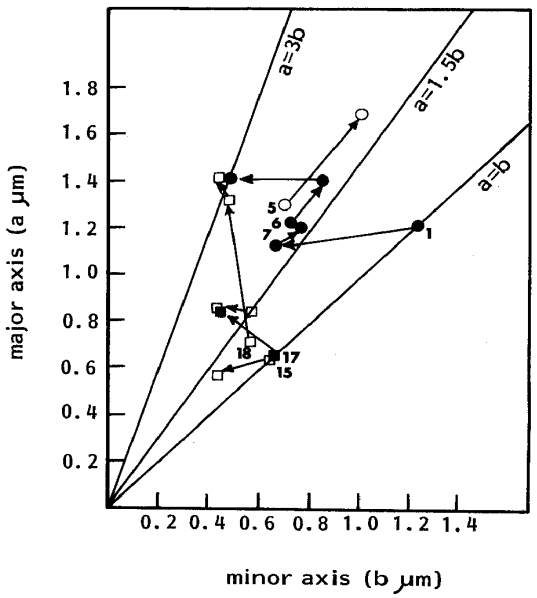


Fig. 18. Pore development in *E. akitaensis* complex through ontogeny. The direction of arrow represents pores of anterior chambers. Legend same as in Fig. 16.

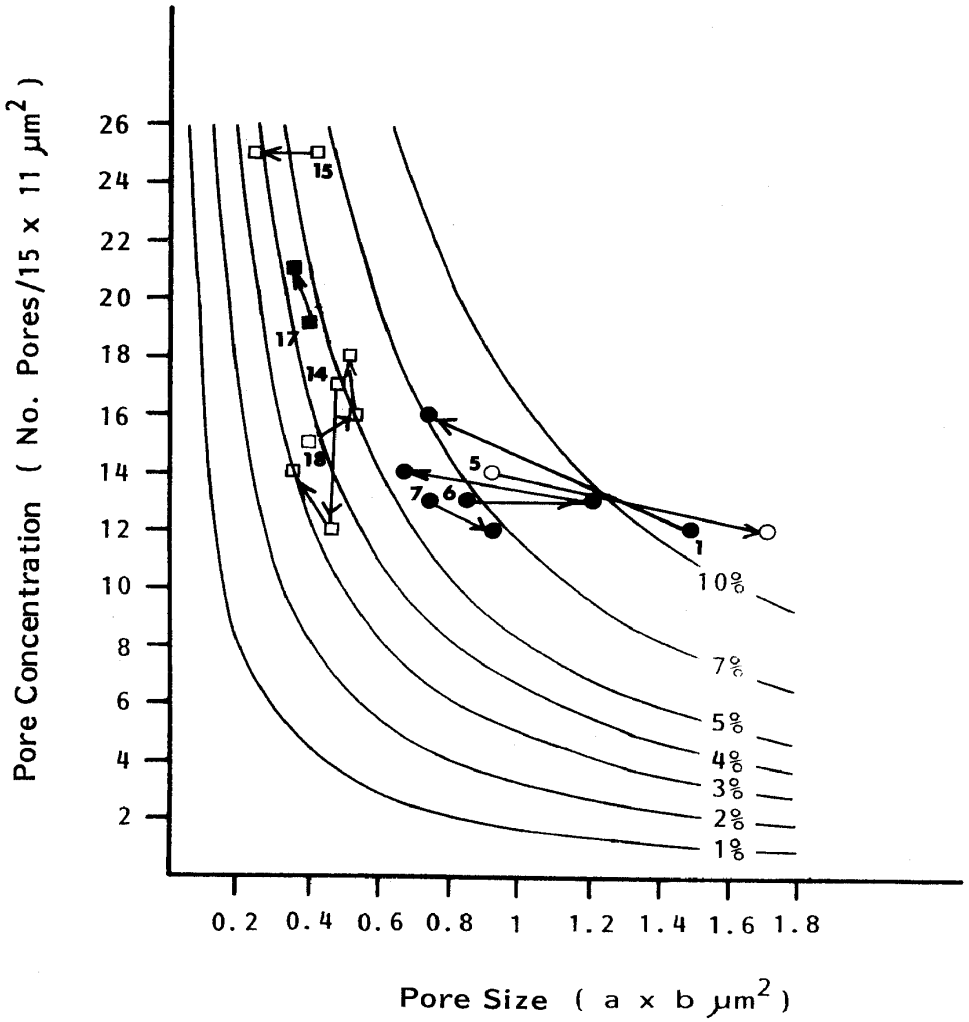


Fig. 19. Shell porosity development in *E. akitaensis* complex through ontogeny. Legend same as in Figs. 16 and 18.

ing and measuring pores. Measurements were made at ×4,500 magnifications on the outer surface of the final chamber and also on the middle and/or early portions of some selected specimens to clarify the ontogenetic change of pores. The number of pores and/or pore concentrations were counted per unit area ($15 \times 11\ \mu m^2$) where the size of pores was measured. The pore size was then expressed by means of the major axis (a) × the minor axis (b) which is slightly more than the actual pore size, and subsequently the mean pore size was figured out. The shape of pores was expressed by the terms, circular (a=b), subcircular (a<1.5b), ovate (a<3b) and slit-like (a>3b). Shell porosity was shown by the percentage of open pore areas to the unit area [(number of pores × mean pore size)/($15 \times 11\ \mu m^2$) × 100].

Figure 16 illustrates the distribution of pore size in *Euuvigerina akitaensis* (Asano) complex including two subspecies, *a. grandis* and *a. pumila*, from 10 localities. This complex shows a wide range of variation in pore size, and no particular distributions of pore size are present between the three morphotypes. The mean pore size ranges from 0.48 μm to approximately

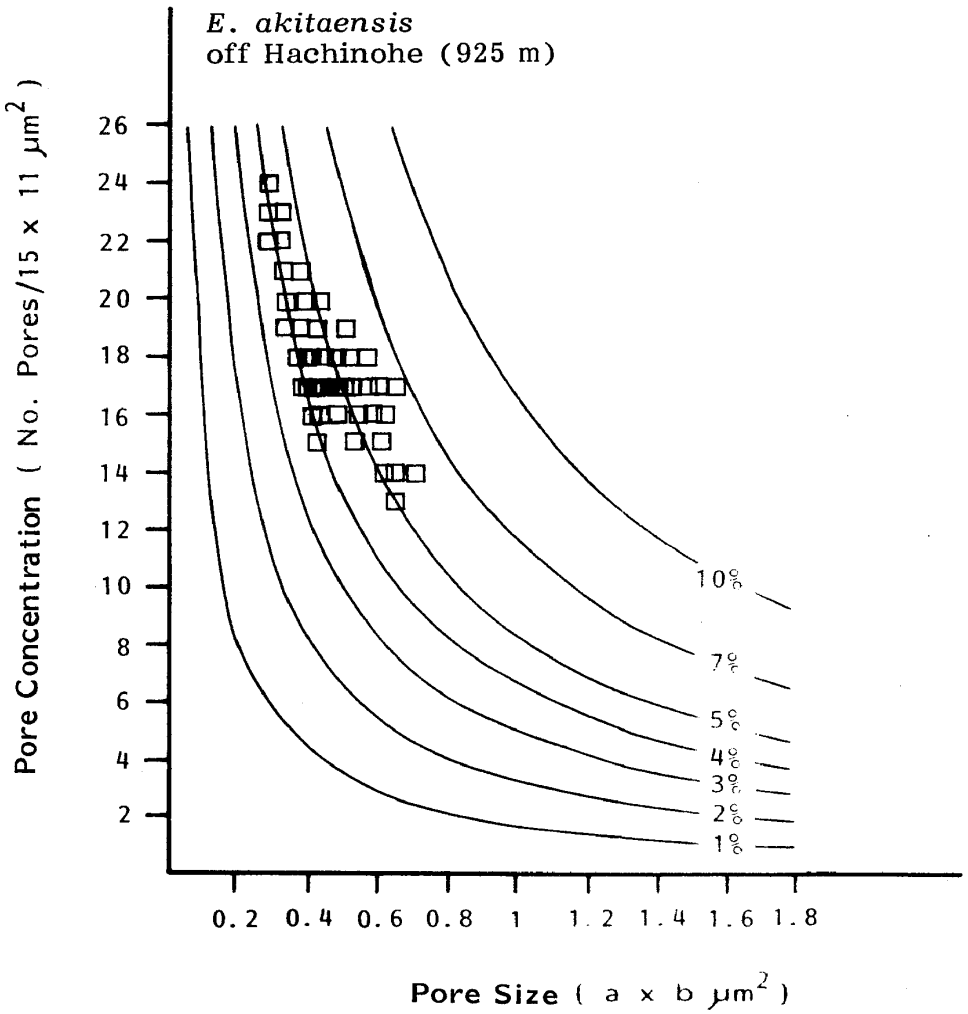


Fig. 20. Shell porosities for 47 specimens of *E. akitaensis* from a single sample off Hachinohe (925 m deep).

three times the dimension (1.22 μm) in cicular pores. The shape of pores is also variable from circular to ovate. It is clear that specimens from the Japan Sea and its coastal areas develop coarser and more elongate pores than those from the Pacific Ocean off Japan and onshore sections facing the Pacific. The full range of pore size in a single specimen was represented by cross bars. Specimens having elongate pores show a wider range of variation in their pore size than those with circular pores.

Figure 17 shows the shell porosities of these twenty specimens. This complex varies from 11 to 25 pores per unit area and from 2 to 12% in porosity. An isopleth of 7% porosity roughly distinguishes specimen groups from the above two distinct provinces. The group from the Japan Sea and its coastal sequences is higher in its shell porosity than the other group. It is noteworthy that the size of pores is negatively correlated to the number of pores; specimens having fewer pores reversely possess greater porosity values in these intraspecific comparisons. Both the number of pores and pore size seem to be responsible for shell porosity, but in reality the latter is more effectual. Then, it may be argued that foraminifera take size strategies for regulating shell porosity.

Figure 18 shows the ontogenetic change of pore pattern in seven specimens selected from the above twenty. It is demonstrated that pores are usually elongated toward the earlier portion of the test — for example, circular to ovate (1, 17) and subcircular to slit-like (18). Only two specimens (6, 7) keep a similar pore shape, but differ in pore size. Here, it should make comment on these elongate pores in the early portion that they are secondarily formed by successively deposited lamellae of subsequently formed chambers. Primitive pores on eariler chambers are much more circular than

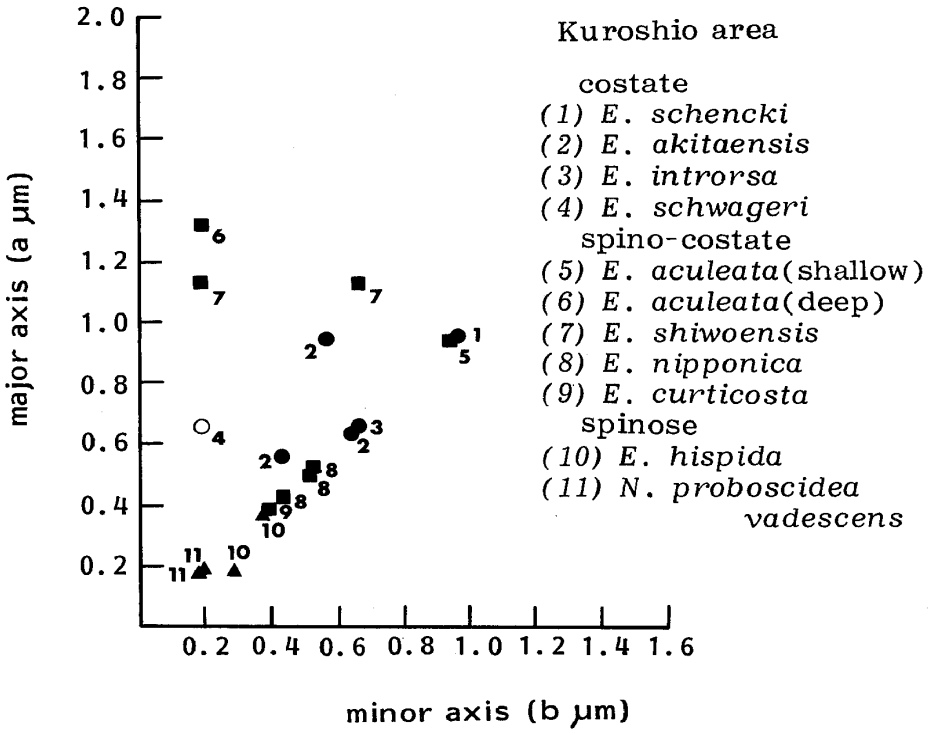


Fig. 21. Mean pore size of ten selected species from Kuroshio area.

those on the lamellate surface.

These ontogenetic changes are illustrated in Fig. 19 together with shell porosities. Porosity values are also variable during ontogeny and their changes with test growth do not show any definite trend. The porosity values of some specimens (5, 7, 18) are higher in the earlier portion of the test than the later. On the other hand, other specimens (1, 14, 15, 17) show lower values in the earlier. Another specimen (6) changes shell porosity zigzag, showing the highest value in the middle portion of the test. The number of pores is more or less stable than pore size through ontogeny. Thus the ontogenetic change of shell porosity is mainly due to the variation of pore size. The above examinations show that the number, size and shape of pores are changeable within a species and are also variable through the ontogenetic development of the tests.

Figure 20 shows shell porosities of 47 individuals in a given population of *E. akitaensis*. The number of pores is variable in the range of 13 to 24, but porosity values are fairly stable, being 5%. This suggests that any given population has constant values both of

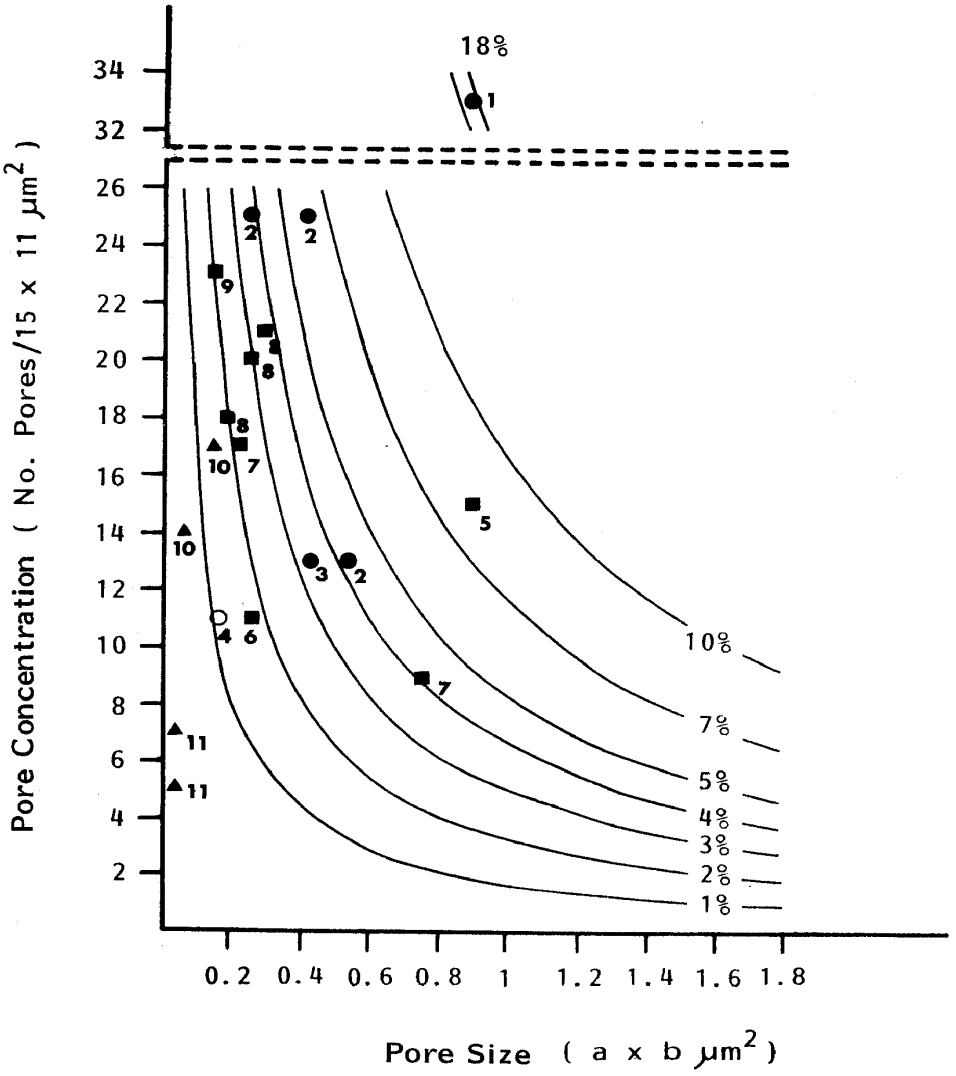


Fig. 22. Shell porosity of ten selected species from Kuroshio area. Legend same as in Fig. 21.

shell porosity and pore size, and then the pattern of pores is principally affected by its environments.

The pore patterns of several species were examined in a given province. Figure 21 shows the pore size and pore shape of ten species including one phenotype from the Kuroshio area. This diagram demonstrates that spinose (triangle) and weakly costate-spinose forms (8) have fine pores. Their pore size usually decreases with increasing water depth. It is noteworthy that deeper inhabitants, *E. nipponica* and *E. hispida*, have fine pores, and shallower inhabitants, *E. schencki* and *E. aculeata*, have coarse pores to the contrary. In addition, the deeper form (6) of *E. aculeata* has elongate and finer pores as compared with its shallower counterpart (5).

Figure 22 shows the shell porosities of these species. A costate form, *E. schencki*, has the highest porosity of 18%, and a spinose form, *Neouvigerina proboscidea vadescens*, has the lowest value of less than one percent. The number of pores is not correlated with the type of ornaments. For example, the spinose form *N. proboscidea vadescens* is more close to the thickly costate-spinose form *E. shiwoensis* than another spinose *E. hispida*. Generally, the deeper and the spinose or weakly costate-spinose form have lower shell porosities than the shallower and the thickly costate-spinose or costate form.

The similar pattern was also recognized at Toyama Bay opening to the Japan Sea. In this province, detected are three morphotypes — the costate and pustulose form *E. kiyoshiasanoi*, the simply costate form *E. akitaensis* and the spinose-costate form *E. lobulata*. Figure 23 shows the pore patterns of these three species. *E. kiyoshiasanoi* is

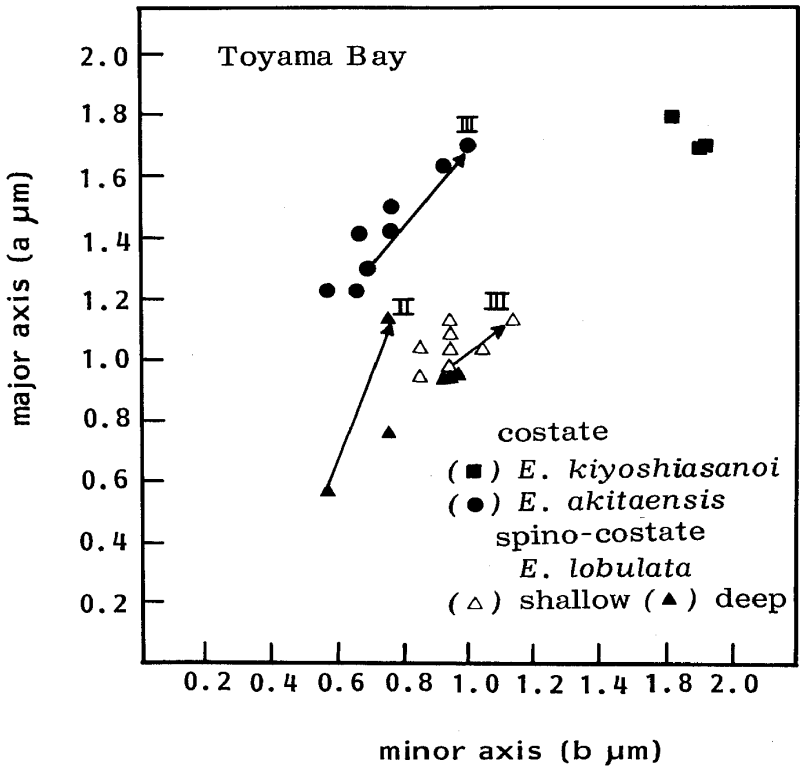


Fig. 23. Mean pore size of three species from Toyama Bay. Measurements are taken at ultimate chamber, except for II (penultimate) and III (antepenultimate).

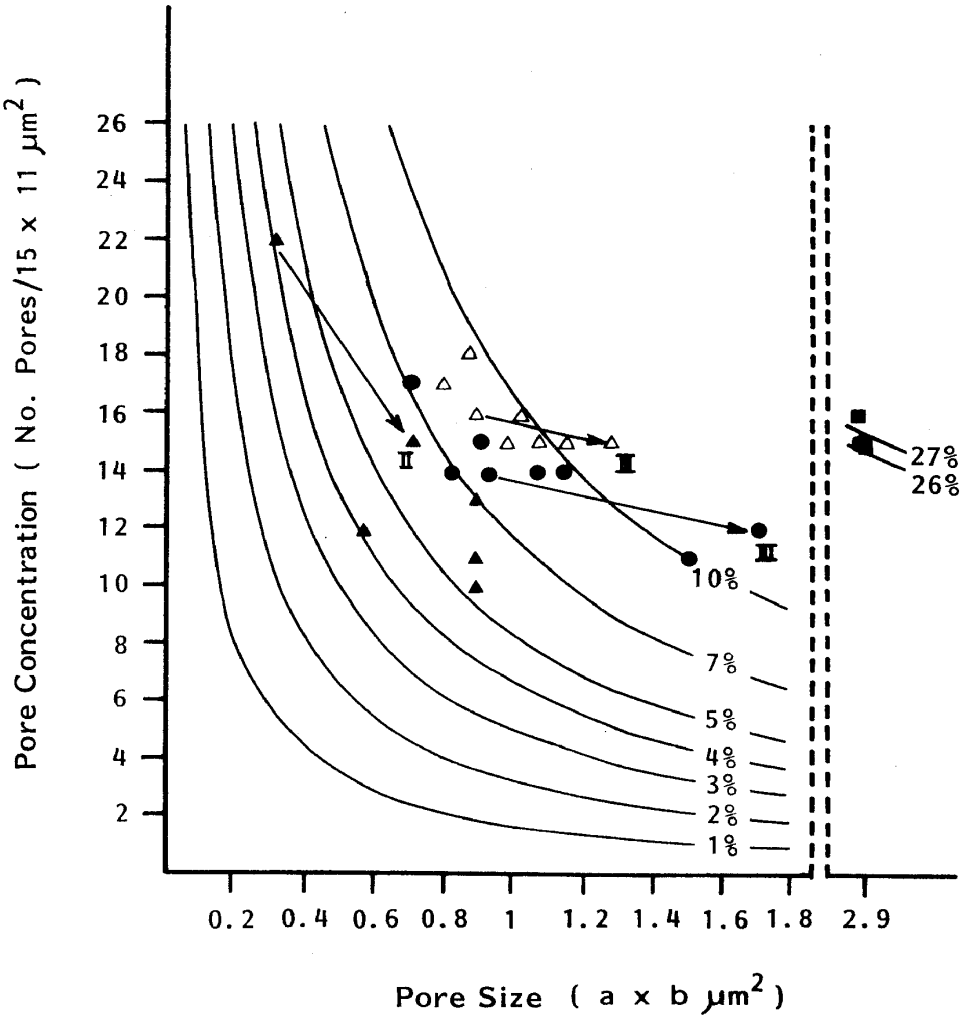


Fig. 24. Shell porosity of three species from Toyama Bay. Legend same as in Fig. 23.

the shallowest inhabitant, and develops coarser pores than the other two species. *E. akitaensis* and *E. lobulata* usually coexist in a deep water mass. Two populations of *E. lobulata* were examined. One population was obtained at a depth of 345 m and the other was at 540 m, where specimens of *E. akitaensis* were also found. Both populations of *E. lobulata* develop circular pores, but *E. akitaensis* possesses elongate pores.

Comparing the porosity values of these species, it is clear that shell porosity is related to water depth (Fig. 24). *E. kiyoshiasanoi* has the highest porosity value of approximately 27%. The shallower population of *E. lobulata* has higher porosity values than its deeper one. The shell porosity of *E. akitaensis* is between those of the two populations of *E. lobulata* and higher than that of the *E. lobulata* population from the same sample. These differences imply that the shell porosity is affected not only by environments or depth but also by test morphology. In this province, the pore size and shell porosity on the penultimate and antepenultimate chambers are coarser and higher than those on the ultimate chamber.

Consequently, the following facts are developed from the above examinations: 1) The number, shape and size of pores are variable within a species and also

through ontogeny. 2) These characters of pores are mainly swayed by environments — for example, water depth. 3) Shell porosity is directly affected by pore size rather than the number of pores. 4) The size of pores and shell porosity are negatively correlated to water depth. 5) Costate forms develop coarser pores and higher shell porosities than spinose forms.

SIZE AND FORM

1. Methods of Study

Six parameters of the test were measured or counted: the length and breadth of a test, the breadth and height of chambers, prolocular diameter and the number of chambers (Fig. 25).

i) Length (L)

This is the total length of a test, and is symbolized by "L". Neither the apertural neck nor apical spine, if any, were included in this measurement.

ii) Breadth (B)

The maximum breadth of a test is symbolized by "B". Ornaments like spines and costae were not included in the measurement. "B" was measured along a line perpendicular to the longitudinal axis.

iii) Chamber breadth (d)

The parameter "d" is the maximum breadth of a chamber which forms the maximum breadth of a test or is situated at the greatest test breadth.

iv) Chamber height (h)

The symbol "h" indicates the height of a chamber, taken perpendicularly to the line of chamber breadth. The wall thickness of the chamber was not included in the measurements of "d" or "h".

v) Prolocular diameter (P.D.)

The internal diameter of a proloculus is indicated by the symbol "P.D.". The wall thickness of the proloculus was not included in the measurement.

vi) Chamber number (Ch.N.)

The parameter "Ch.N." is the total

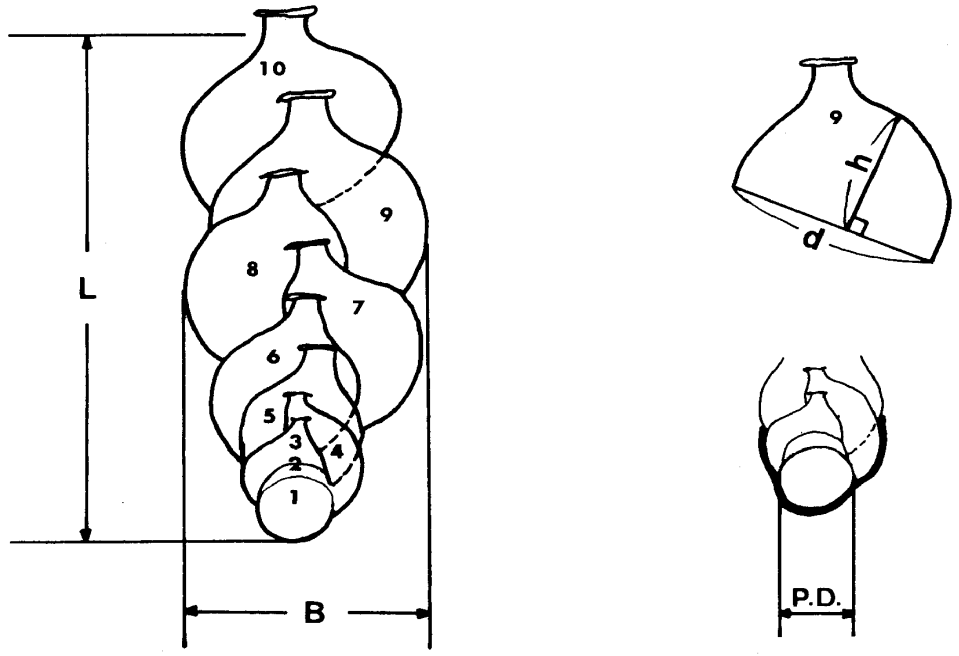


Fig. 25. Schematic illustration showing measured or counted parameters.

number of chambers, including a proloculus.

For the above morphological analyses of uvigerinid foraminifera, two methods were employed for observations ; binocular microscopy and contact microradiography (C.M.R).

Soft X-ray radiography is well adopted in morphological studies, because this technique provides a speedier and nondestructive method for investigating an internal structures. Its usefulness in the study of foraminifera has already been documented by Hedley (1957) and Hooper (1959). In the present study X-ray radiography was used for measuring prolocular diameter, chamber breadth, and chamber height, and for counting the number of chambers. This technique is also applied for observing the morphology of toothplates. A SOFTEX type C-SM was employed for microradiography.

The procedures of X-ray absorption techniques are as follows :

i) Affix a small piece of sellotape to one side of the sample ring (15 mm in diameter).

ii) Mount specimens on the adhesive side of the sellotape.

iii) Place cut X-ray film (Kodak # 649-0) on a magnetic cassette in the dark room.

iv) Place the prepared sample ring on the film keeping a specimen-bearing surface upward. Though specimens indirectly contact with photographic emulsion, they are tightly fastened to the film by a magnetic cassette.

v) Set the cassette to the holder of a X-ray diffraction equipment at a distance of 60 mm from the focus of X-ray tube.

vi) Penetrate X-ray. Exposure times were about 25 minutes at 5 mA, 95 kV, but varied from 15 to 50 min. according to the wall thickness of specimens.

vii) Remove the sample ring and film from the magnetic cassette. Examined specimens can be easily removed from the adhesive tape by immersing them in a water droplet and gently patting them with a fine brush.

viii) Develop the film by standard treatments of Kodak Maximum Resolution Plate.

ix) Wash and dry the film in a dust-free atmosphere. At this step the film is ready for microscopic examination.

x) For keeping the film clean, place it on a slide glass and put cover glass on it, and then stick cover glass fast to the slide glass with sellotape.

xi) Observe the film under 20× to 50× magnification with an optical microscope.

The breadth and length of a test were measured through binocular microscopy or contact microradiography. The other morpho-parameters were examined by using only contact microradiography.

2. Size Variation

Euuvigerina akitaensis (Asano) complex, including two subspecies (*a. grandis* and *a. pumila*) was subjected to the analysis of size variation. The purpose in this section is to clarify whether test size is influenced by environmental factors and which morpho-parameter is related to size variations. Examined are six morpho-parameters : the length and breadth of a test, prolocular diameter, the breadth and height of a chamber, and the number of chambers. Four out of prepared thirteen materials were selected for measurement. Only the length and breadth of a test were measured using the remaining nine materials. These materials are from Late Miocene to Recent sediments in the Japan Sea and the northwestern Pacific Ocean, and their coastal areas of Japan.

The distribution of the mean test size (B/L) in *E. akitaensis* complex from thirteen localities is depicted in Fig. 26.

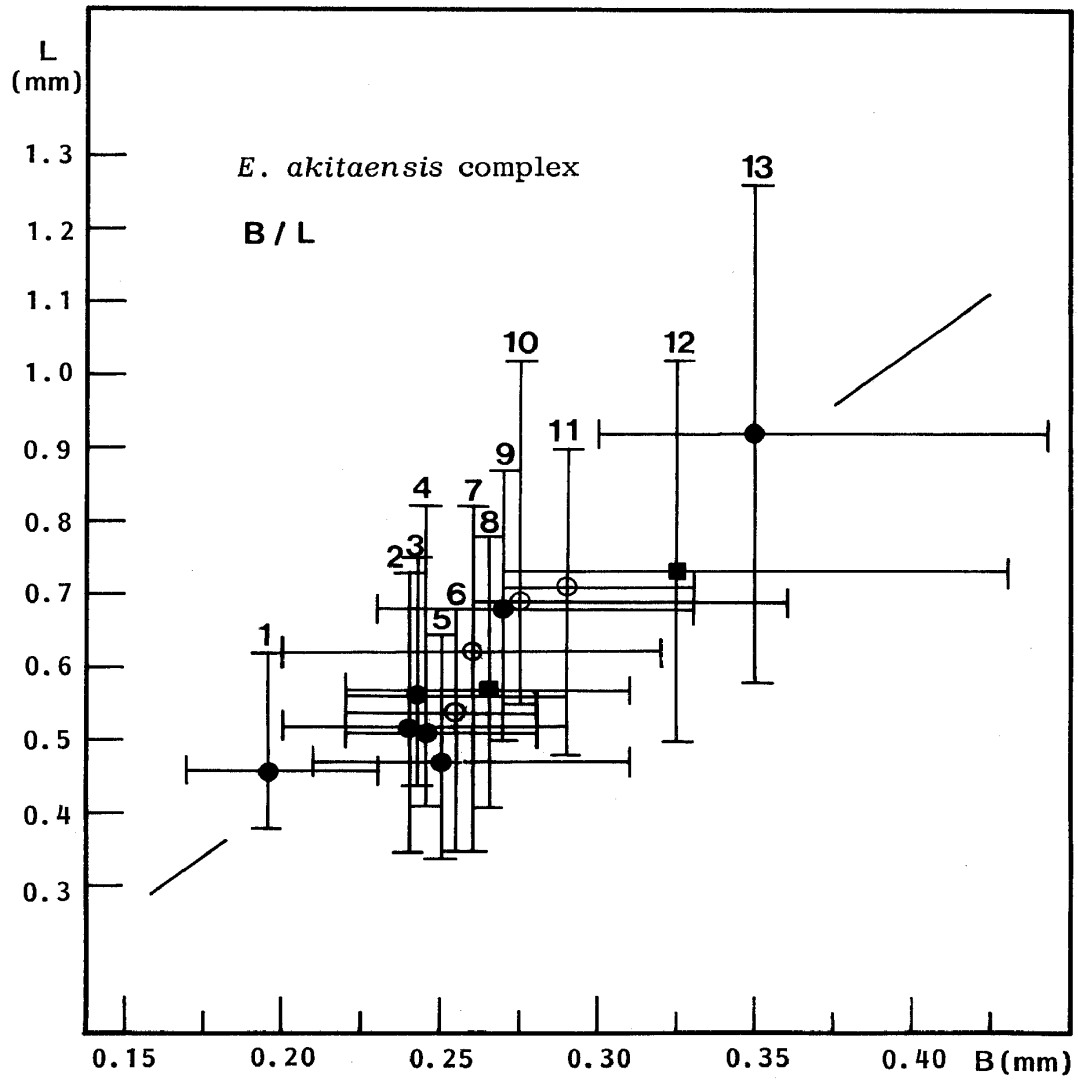


Fig. 26. Mean test size distributions (breadth vs. length) of *E. akitaensis* complex in 13 selected samples. 1 : subsp. *pumila* ; 2–12 : typical form ; 13 : subsp. *grandis*. Solid symbol : fossils ; open symbol : Recent. Square : Asano's collection.

A cross bar indicates the total range in each samples. Though the typical forms are more or less clustered in their test sizes, this complex shows wide variations. The test size of an end-group, *a. grandis* (13) is almost twice that of an opposite end-group, *a. pumila* (1).

Recent specimens (6) from Toyama Bay are smaller than those (7, 8 and 9) from the Pacific side. In the Pacific, the specimens (8 and 9) from the Transition area are larger than those (6) from the Kuroshio area. *E. akitaensis* is different in depth distribution among the above three geographical provinces ; 800 to 2,000 (?) m in the Transition area and 250 to 1,000 m in the Japan Sea, and only a few specimens are found at Enshu-nada in the Kuroshio area at depths from 400 to 800 m.

Fossil specimens (2, 8, 12 and 13) from the Oga Peninsula vary in test size, extending nearly all over the range of those in *E. akitaensis* complex, except for *a. pumila*. Their test size decreases from sample to sample with increasing

progradation. For example, specimens in sample (13) from the uppermost part of a siltstone layer in a turbidite sequence outcropping at the sea cliff west of Oibanazaki have the greatest test size in this complex. The turbidite composed of siltstone-dominating alternations of siltstone and sandstone seems to have been deposited in the upper bathyal zone. Associated benthonic forms are also bathyal species such as *Islandiella norcrossi* (Cushman) and *Cassidulina norvangi* Thalmann. On the other hand, specimens (2) from sandy siltstone distributed along the Anden coast are much smaller in test size. This sandy silstone of the Wakimoto Formation was deposited in the outer sublittoral zone. The assemblage of benthic foraminifera also shows a shallow water facies with the occurrences of *I. sublimbata* (Asano and Nakamura) and *Elphidium clavatum* Cushman. Specimens in sample (1) from the

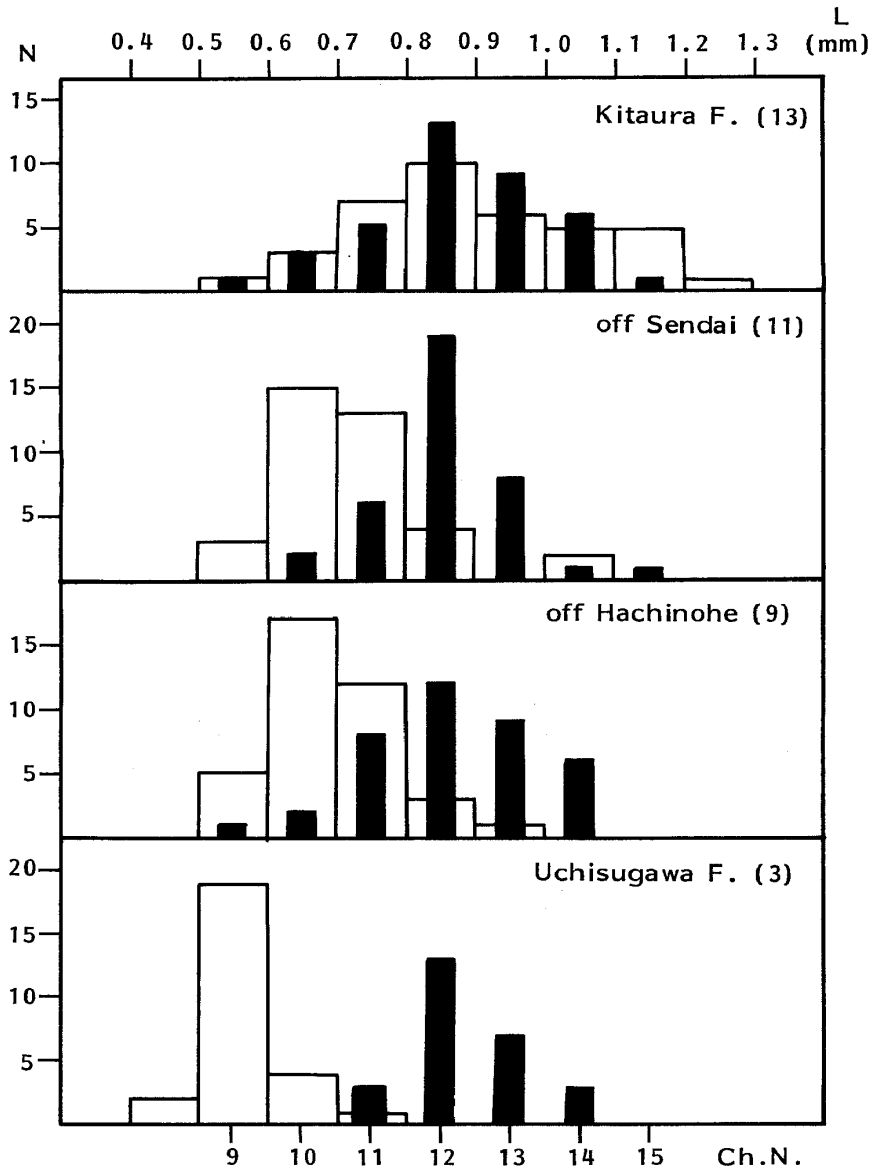


Fig. 27. Histograms of number of chambers (Ch. N., closed) and test length (L, open) of *E. akitaensis* complex in four selected samples.

uppermost part of the Umegase Formation distributed in the Boso Peninsula have the smallest test size in this complex. Aoki (1965) reported this small morphotype, which is here assigned to subsp. *pumila*, from central shelf sediments in other formations. Specimens in sample (5) from the middle part of the Umegase Formation have, however, broader tests than subsp. *pumila* and are close to Asano's specimens (8) from the type locality. Specimens from the uppermost part of the Late Miocene Uchisugawa Formation in Niigata Prefecture (3) and those from the lower part of Pliocene Yabuta Formation in the Himi area (4) are both small in test size. Hasegawa (1979) mentioned that the lower part of the Yabuta Formation commonly contains benthic foraminifera which might be distributed in a shallow water mass in the Oyashio area.

Summarizing the above facts, the test size of such forms is changeable according to their environments. Larger tests are developed under colder and deeper environments in the case of *E. akitaensis* complex.

To clarify whether size variations are directly affected by the number of chambers, test length is compared with the number of chambers in four selected samples (3, 9, 11 and 13). Because foraminifera show dimorphism (the microspherics and megalospherics) in the number of chambers, only the megalospheric specimens are used for comparisons. From Fig. 27, it is clear among populations that the number of chambers does not contribute to the variations of test length. All the four examined populations show a normal distribution in the number of chambers and have their peaks at twelve chambers. Though large specimens have more chambers in a given population, this is ascribed to foraminiferal ontogeny. Examination of specimens with the same number of chambers shows that test size is stable within a given population, but greatly varies from population to population. For instance, specimens in sample "3" show an almost identical frequency distribution of number of chambers with those in sample "13", having a peak at twelve, although the former is much smaller than the latter. Thus the number of chambers does not affect size variation among ecophenotypes.

Four morpho-parameters, the length and breadth of test, and the breadth and height of chambers, are plotted in Fig. 28. The chamber size of *E. akitaensis* complex rapidly increases at the juvenile stage, but is almost unchanged from the antepenutimate chamber in usual cases. Near the antepenultimate chamber, the test is greatest in breadth, and then it more or less loosely coils, adding the last-formed two chambers, but no more increases in chamber size. As already mentioned in the section of parameter, the chamber size of each specimen was measured at a chamber which makes the test maximum in breadth. It is suggested that test size is congruent with chamber size. That is, larger chambers lead to larger tests. Most chambers are 1.6 times as broad as high.

When the height and breadth of chambers are respectively correlated with the length and breadth of tests, a positive relationship will be more clearly documented between test size and chamber size. The distribution patterns of chamber breadth versus test breadth and chamber height versus test length were examined (Fig. 29). It is easily recognized that the above two comparisons show positive relations between test size and chamber size. The breadth of chambers and tests (d/B) is more sharply correlated as compared with the relationship between chamber height and test length (h/L). Generally, test length is five times the chamber height and test breadth is 1.3 times the chamber breadth,

but subsp. *grandis* has slightly lower d/B and h/L ratios than other typical forms.

Figure 30 shows the distribution of prolocular diameters with those of test size. Microspheric specimens are not included in the frequency distributions of test size, because they were not detected in samples "3" and "9". The prolocular diameters of megalospheric specimens of *E. akitaensis* complex range widely from 50 to 130 μm, though the microspherics are uniform, having proloculi of 20 μm. Only a few microspheric specimens occurred together with megalospheric ones from samples "11" and "13". There is a distinct break in prolocular diameter between the microspherics and megalospherics. The diameters of megalospheric specimens show a positive relationship with test

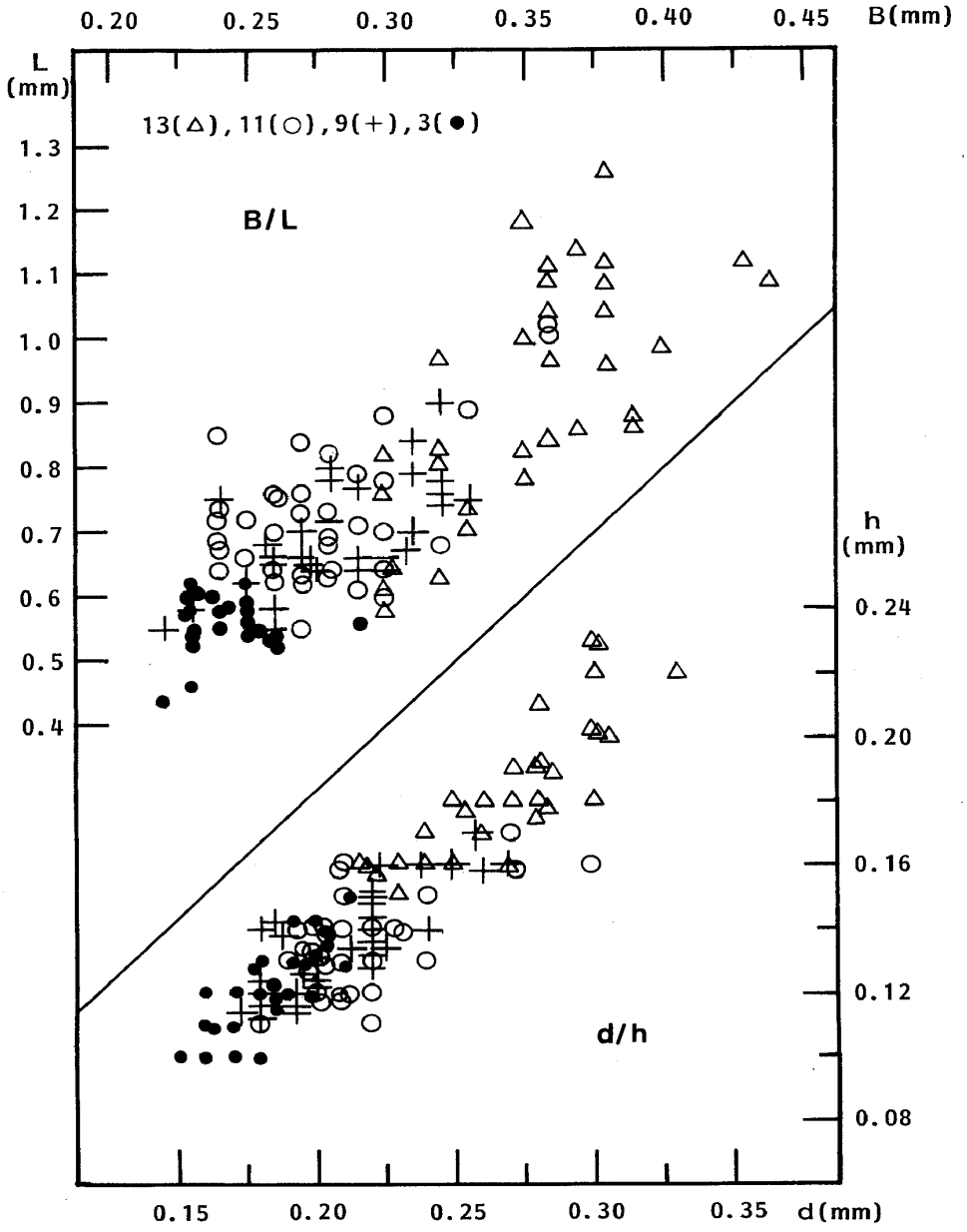


Fig. 28. Scatter-diagrams of test breadth (B) versus test length (L), and chamber breadth (d) versus chamber height (h) in *E. akitaensis* complex in four selected samples. Samples same as in Figs. 26 and 27.

size. If samples "2" and "13" are pooled, the frequency distribution of prolocular diameters is trimodal with peaks at 20, 60 and 80 μm just as in *Afrobolivina afra* (Reyment, 1959). This phenomenon is only attributed to the fact that larger tests have larger megalospheric proloculi, not to trimorphism. Any distinct break is not established for megalospheric specimens in a given population. The prolocular size is variable with environments, as is the case of test size.

3. Growth Pathway

In order to follow the growth pathway, the length and breadth development through ontogeny of eight euuvigerine species is given in Figs. 31, 32 and 33. Five species indicated by closed symbols (*Euuvigerina aculeata*, *E. shiwoensis*, *E. hispida*, *E. nipponica*, n. sp. and *E.*

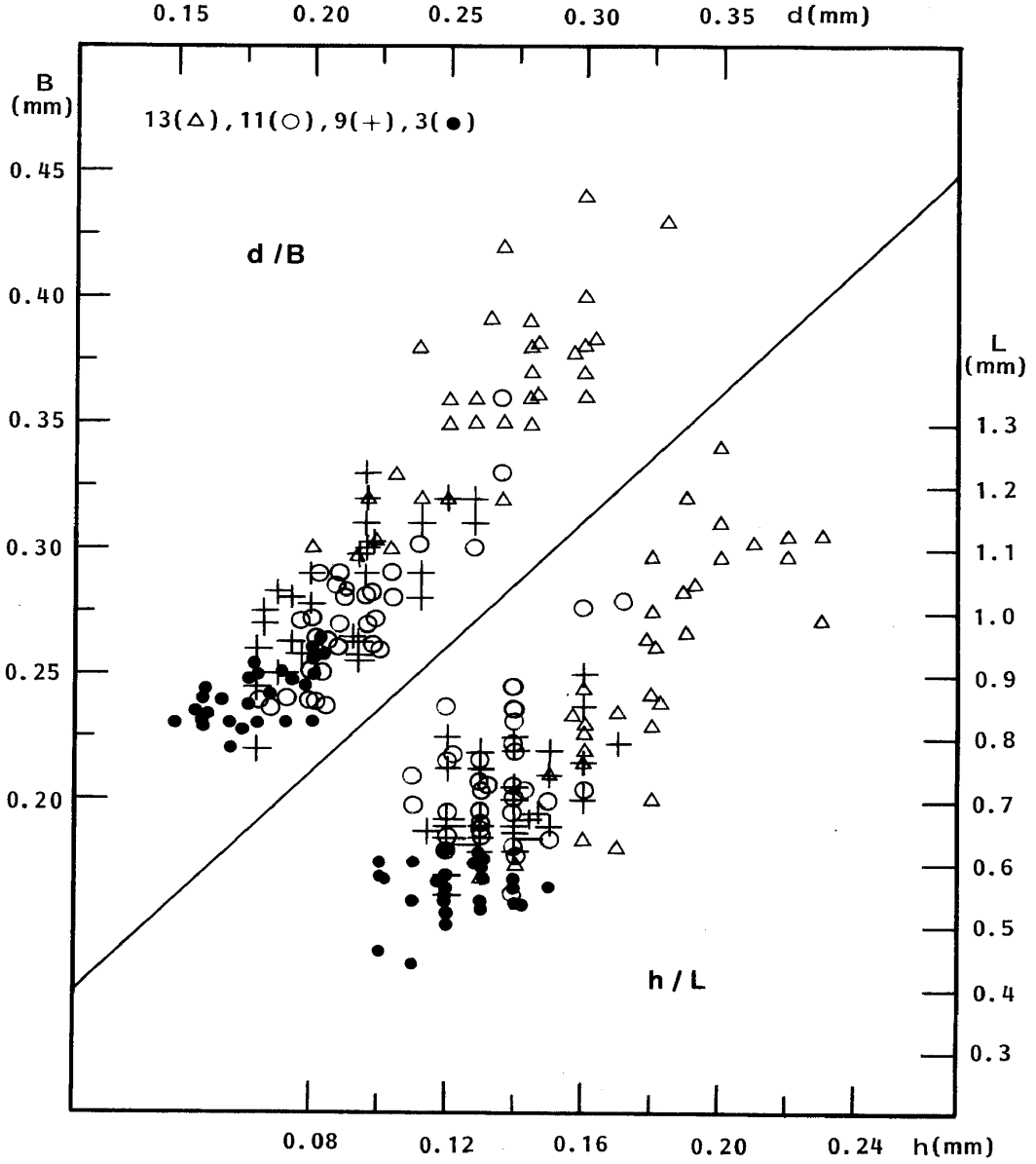


Fig. 29. Scatter-diagrams of chamber breadth (d) versus test breadth (B), and test length (L) versus chamber breadth (h) in *E. akitaensis* complex in four selected samples. Samples same as in Figs. 26 and 27.

akitaensis) are widely distributed on the Pacific side of Japan. Three species plotted by the open symbols (*E. kiyoshiasanoi* n. sp., *E. lobulata* n. sp. and *E. schencki*) occur in bottom sediments of the Japan Sea. All examined specimens are Recent megalospheric ones and represent typical materials for comparisons of growth pathway among species and also biogeographical provinces. Though *E. akitaensis* occurs on both the Pacific and Japan Sea sides, it is more dominant and develops larger tests in the Oyashio and Transition areas of the Pacific than in the Japan Sea. The examined specimen of *E. akitaensis* is from the Transition area which is a mixed zone of cold and warm water

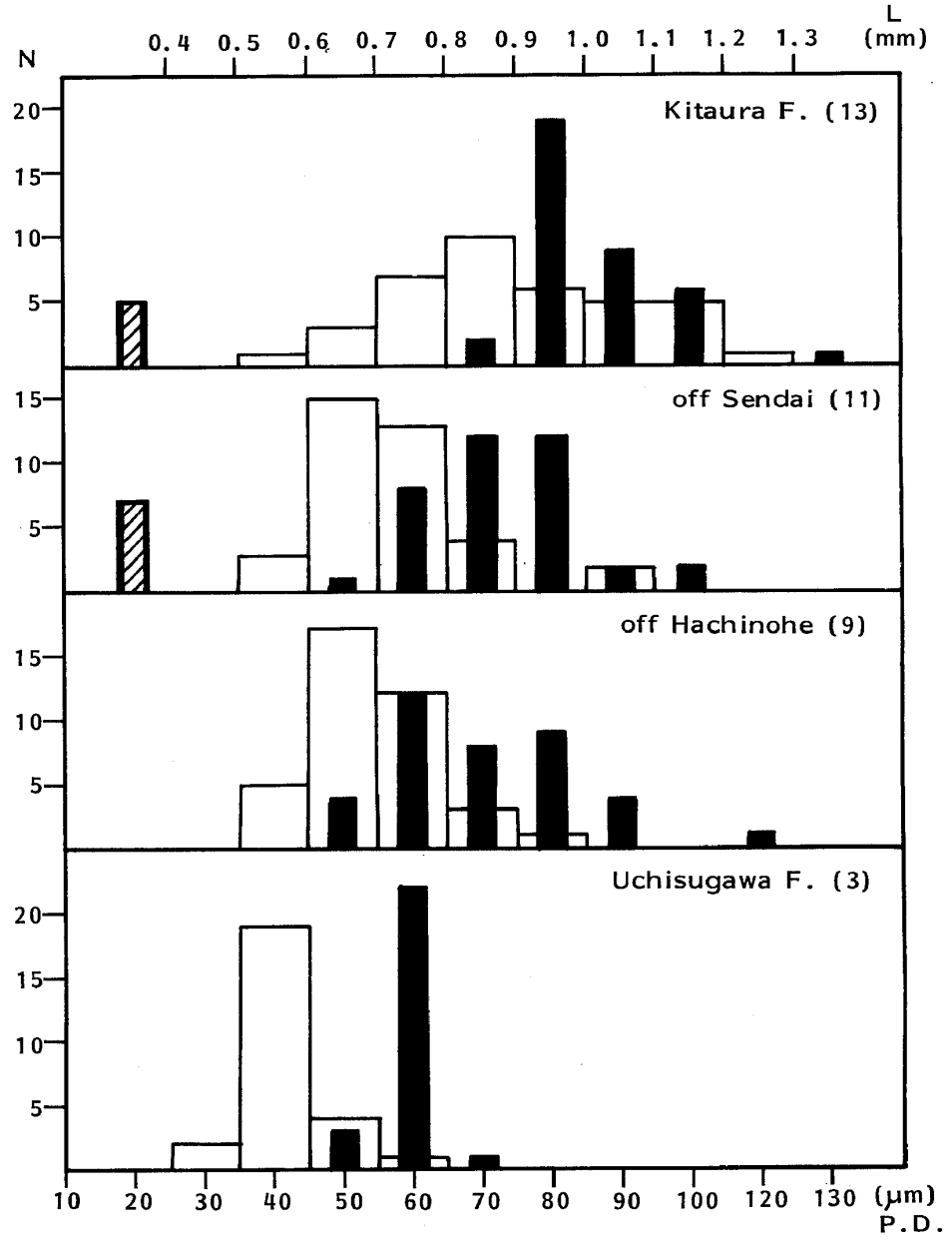


Fig. 30. Histograms of prolocular diameter (P.D., closed, hatched) and test length (L, open) of *E. akitaensis* complex in four selected samples. For hatched specimens no data available to frequency distributions of test length.

masses. The other four species from the Pacific are peculiar to the warm Kuroshio area. Two new species, *E. lobulata* and *E. kiyoshiasanoi*, exist in the cold Japan Sea Proper Water. *E. schencki* is very sparsely distributed near the Tsushima Straits, but is typical species in this area.

Here, a basic question may be raised as to whether growth pathway of euuvigerines is dependent on biogeographical provinces; in other words, whether euuvigerines in a given province have peculiar patterns of growth pathway.

Figure 31 shows that five species from the Pacific have much broader and larger tests than three species from the Japan Sea. The growth pathway of *E. akitaensis* establishes the boundary between those of species from the Japan Sea and the Pacific. *E. akitaensis* from the Transition area is more slender than the other four species from the Kuroshio area in the Pacific. E. *aculeata* and *E.*

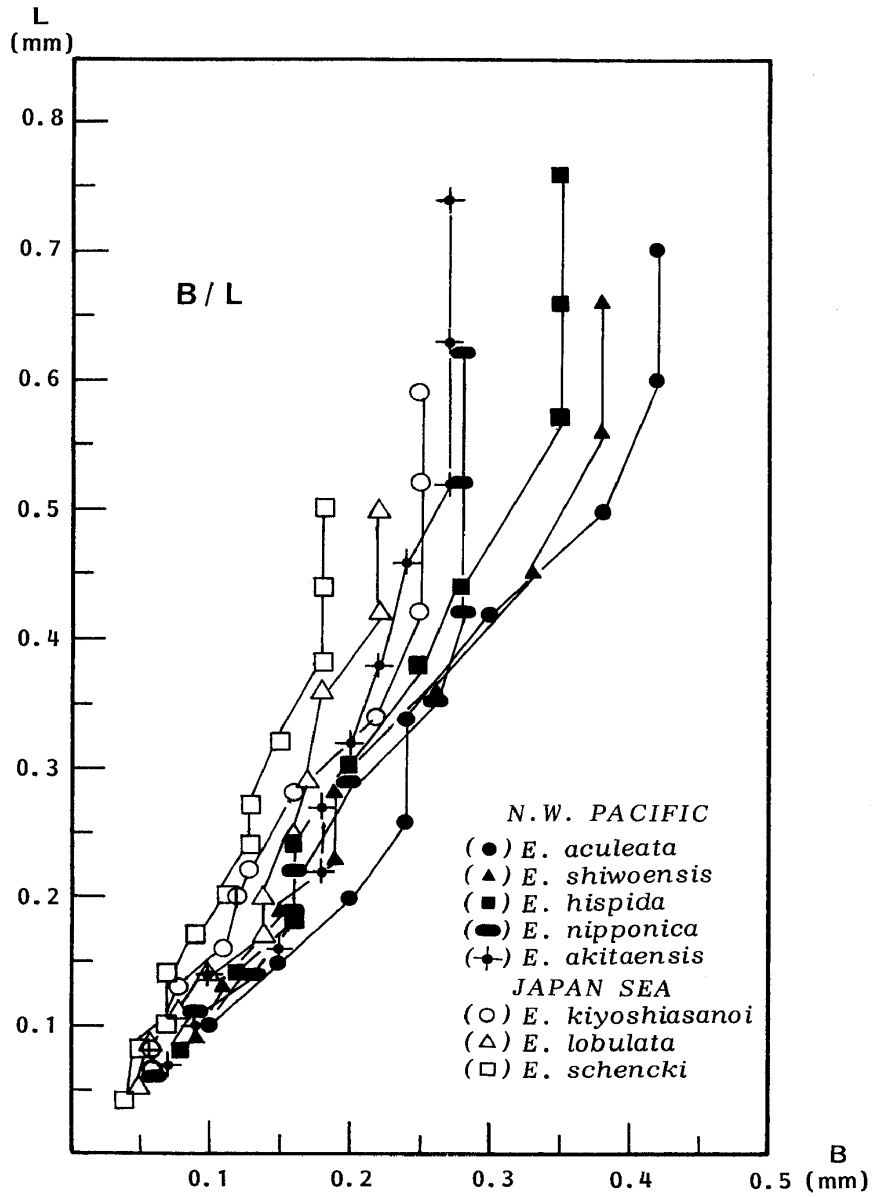


Fig. 31. Length and breadth development of eight selected euuvigerine species through ontogeny. All are megalospherics.

shiwoensis are distributed at shallower depths than E. *hispida* and *E. nipponica* in the Kuroshio area. The former two species develop much broader tests than the latter two. In the Japan Sea, *E. lobulata* is a deeper morphotype and also has more slender tests than *E. kiyoshiasanoi*. Though *E. schencki* is a shallower inhabiting species, it forms more slender tests than the above two species.

The test length is plotted as a function of number of chambers in Fig. 32. The species from the Kuroshio area has larger chambers as compared with that from the Japan Sea, but the former has a smaller number of chambers (9 to 10) than the latter (11 to 12). At the same time, growth in length for each chamber episode gradually increases toward the later stage in all the examined species. Then, lines L/N do not show integral relationships. As a whole, the test length successively increases in an

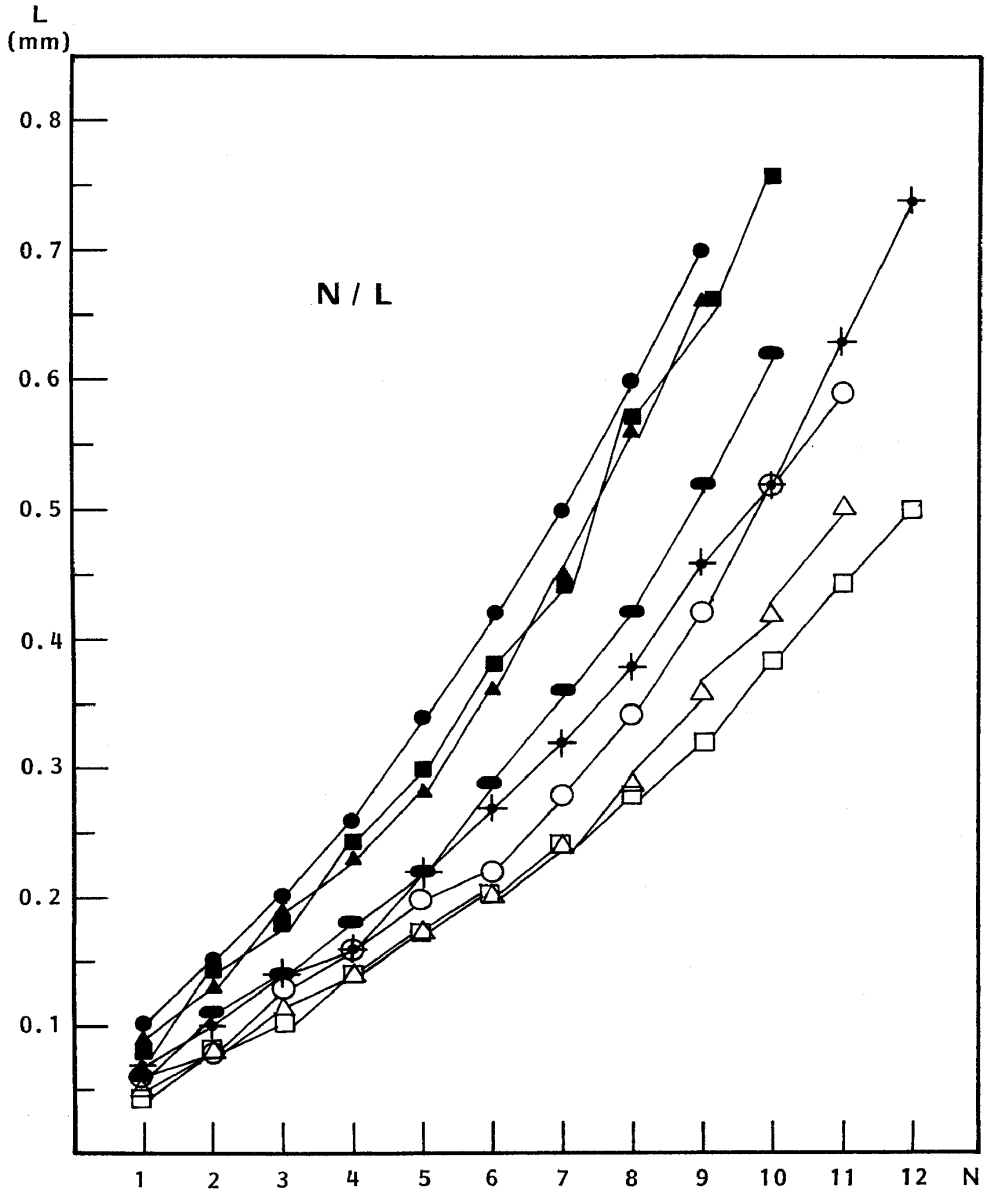


Fig. 32. Test length as a function of number of chambers. Legends same as in Fig. 31.

arithmetic series.

The ontogenetic development of test breadth is shown in Fig. 33. All species reach the maximum test breadth at the stage of the antepenultimate or penultimate chamber. When the last-formed chambers are added near the coiling axis and bi- to uni-serial arrangements develop, the test breadth is relatively reduced in later portions. In this study, breadth was measured at the greatest portion at a given stage. The successive lines of B/N can be segmented by depressed portions in growth gradient. Such depression can be detected at the stage of the 5th chamber in *E. aculeata*, *E. shiwoensis* and *E. nipponica*, and at the 4th chamber in *E. hispida*. Though the depression is overestimated owing to plane measurements, after this depression, chamber size abruptly increases. Three species from the Japan Sea do not show so distinct depression, and gradually increase its test breadth through ontogeny.

The above observation leads to the following lines: 1) If the number of chambers can be equated with the foraminiferal age, warm water species more rapidly grow into adulthood than cold water ones. 2) More slender morphotypes are generally inhabitable the cold water province or deeper haunts. 3) Warm water species more rapidly increase its test size than cold water species. 4) Euuvigerine foraminifera in a peculiar geographic province have their own growth pathways which are

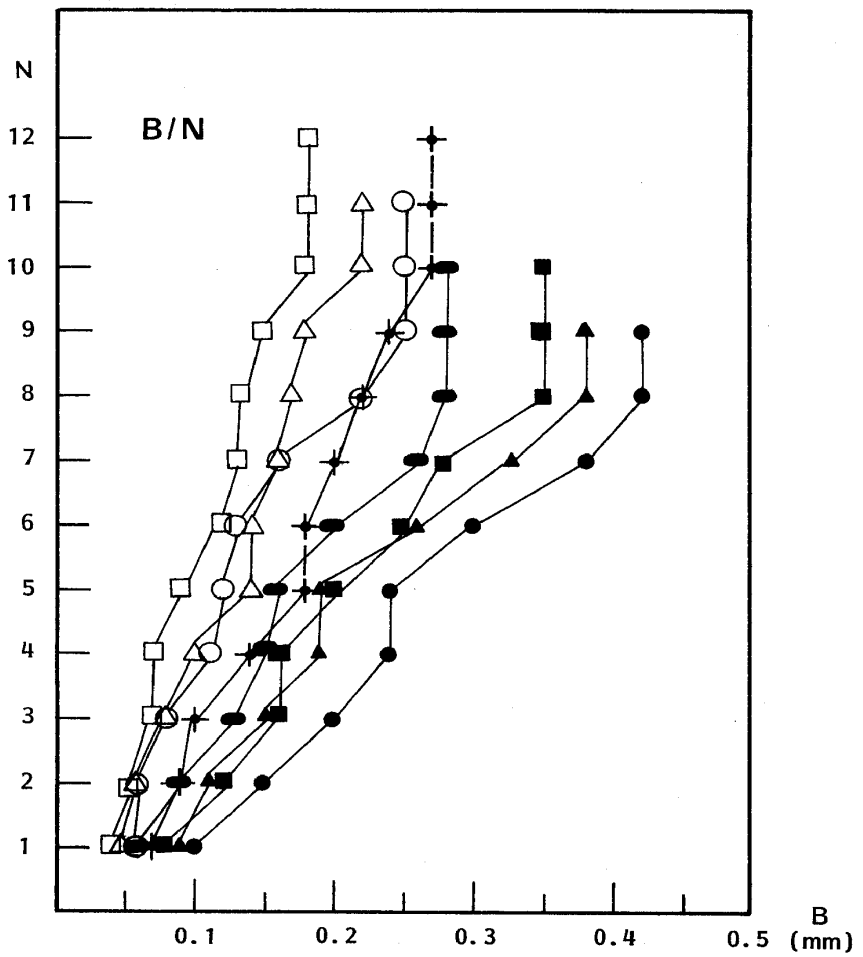


Fig. 33. Test breadth as a function of number of chambers. Legends same as in Fig. 31.

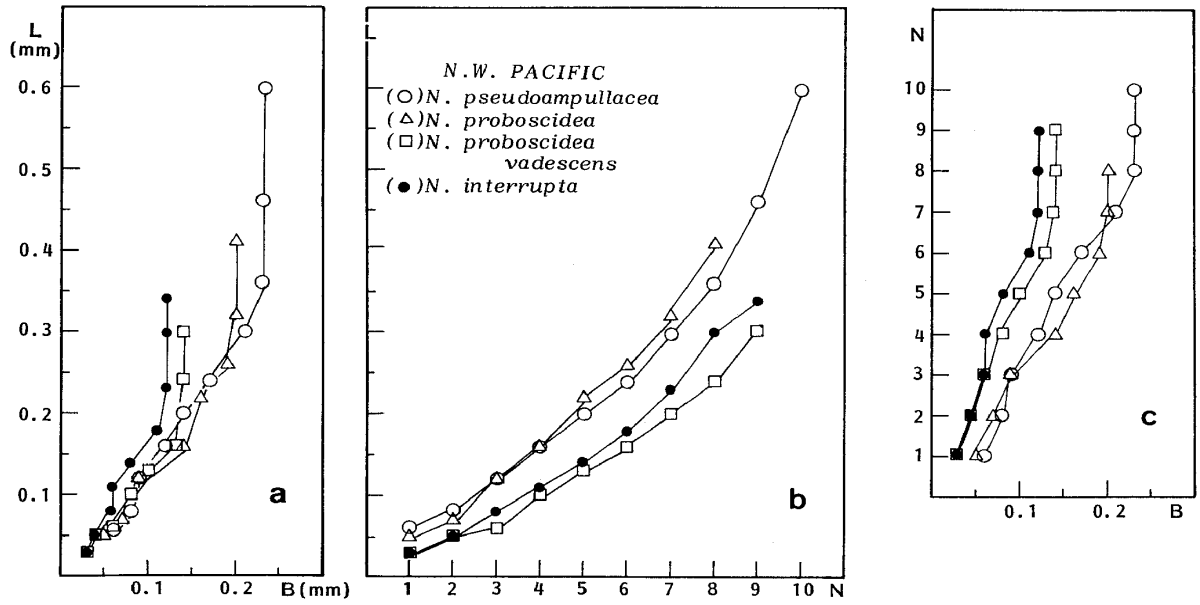


Fig. 34. Growth pathways of four selected neouvigerine species. All are megalospherics. a : test breadth versus test length, b : number of chambers versus test length, c : test breadth versus number of chambers.

restricted by their environments.

As mentioned above, three species from the Japan Sea show similar growth pathways, but *E. schencki* is distributed through the warm Tsushima Current and the other two species inhabit the cold Japan Sea Proper Water area. Then, the growth pathway is a genetic consequence and selective under external stresses or environments, and then is not subject to changing environments. *E. schencki* is probably strongly stressed under unsuitable environments, and then its occurrence is very rare.

Neouvigerine species is only distributed in the Kuroshio area. The growth pathways of four selected species (*Neouvigerina pseudoampullacea* (Asano), *N. proboscidea* (Schwager), *N. proboscidea vadescens* (Cushman) and *N. interrupta* (Brady)) are illustrated in Fig. 34. These forms are terminated with 8 to 10 chambers, which number is similar to euuvigerine species from the Kuroshio area. Their greatest breadth is observed at the antipenultimate chamber. The growth in length for each chamber episode gradually increases through ontogeny. These two characteristics are also found in euuvigerine species, but neouvigerine species generally have smaller tests.

4. Dimorphism

It has been documented that foraminiferal dimorphism can be detected in the number of chambers, prolocular diameter and test size (Hofker, 1951 ; Reyment, 1959 ; Sliter, 1970 ; Jonkers, 1984). Eight euuvigerine and four neouvigerine species were selected for the study of prolocular dimorphism. They are identical with the species examined at the section of Growth Pathway. The frequency distributions of their prolocular diameters are shown in Fig. 35. Of the twelve species only five show a distinct break in the distribution of prolocular diameters. All these five species (*E. kiyoshiasanoi*, *E. lobulata*, *E. akitaensis*, *E. aculeata* and *E. hispida*) have a peak at 20 μm which represents one mode of the bimodal distributions. The other mode is distributed in various ways. The percentage of microspheric specimens is very low in a given

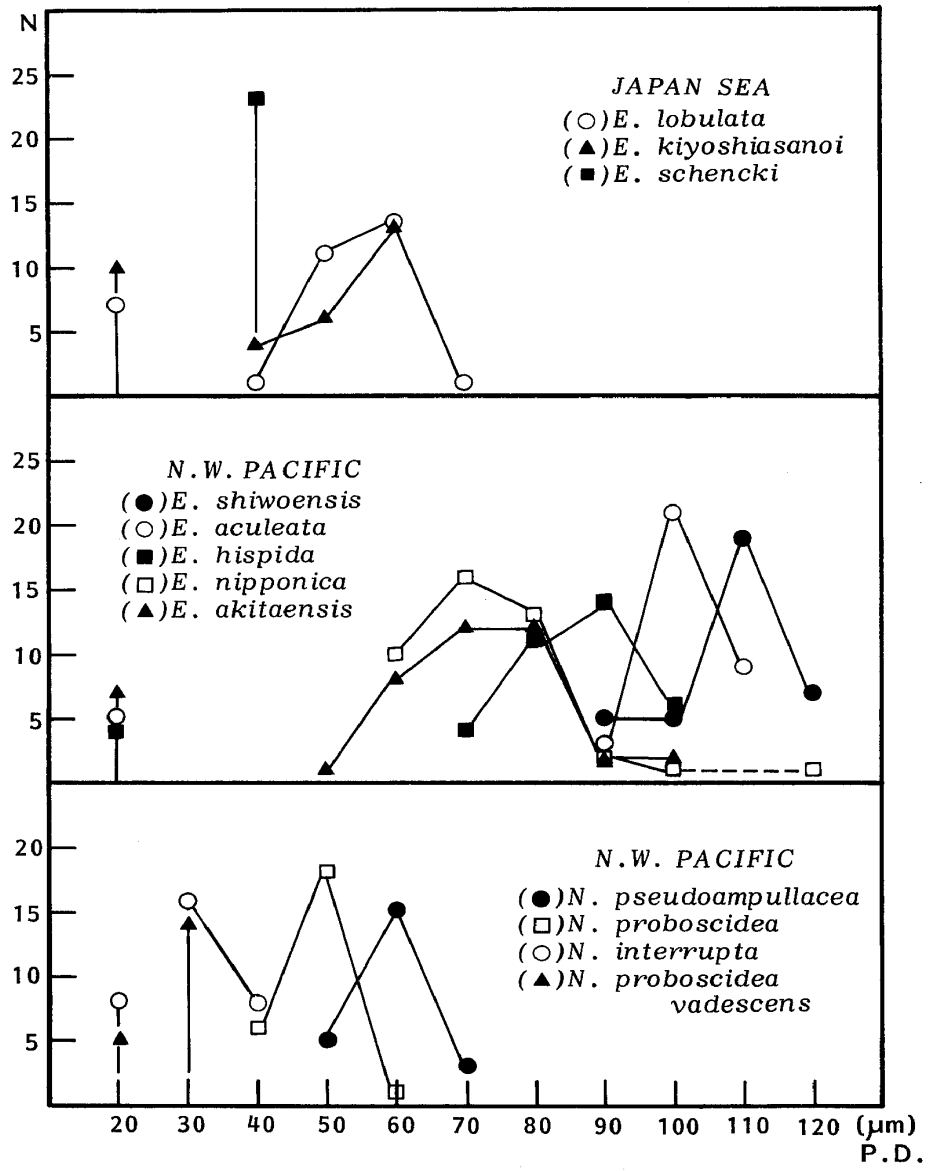


Fig. 35. Frequency distributions of prolocular diameters in 11 species and one subspecies.

population. The other seven species do not show bimodal distributions. For example, the proloculi of *E. shiwoensis* range from 90 to 120 μm, with a peak at 110 μm. These comparatively large proloculi suggest that *E. shiwoensis* has occurred with asexual reproduction in examined population. The above facts imply uvigerinid species usually proliferates asexually. *Neouvigerina interrupta* and *N. proboscidea vadescens* also have a proloculus of 20 μm, which is referable to that of the microspherics of euuvigerine species. They do not have, however, any distinct break in the distributions of prolocular size. As a whole, neouvigerine species have a smaller proloculus than euuvigerine ones from the same province.

In asexual generations, euuvigerine species from the Pacific side of Japan have a much larger proloculus than those from the Japan Sea. This phenomenon is well related to that in the pattern of growth pathway or test form. As already mentioned in the section of

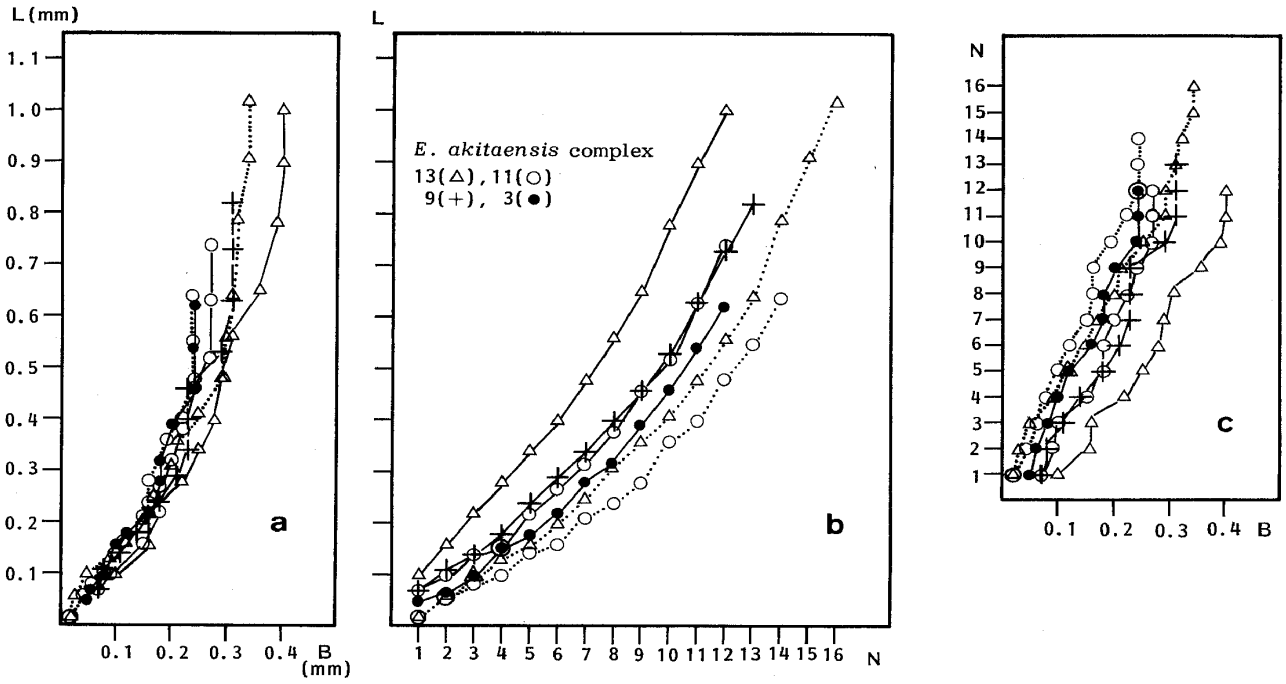


Fig. 36. Growth pathways of *E. akitaensis* complex in four selected samples. Solid line: megalospherics; dotted line: microspherics. a: test breadth versus test length, b: number of chambers versus test length, c: test breadth versus number of chambers. Samples same as in Figs. 27 and 30.

Growth Pathway, euuvigerine species from the Pacific more rapidly attains full growth and develops a much broader test than that from the Japan Sea. Then, species having a large proloculus more rapidly mature and form a broader test than species having a smaller one. The prolocular size of the megalospherics is very flexible to their environments (see the section of Size Variation).

The growth pathways were compared between the megalospherics and microspherics for six selected species such as *E. akitaensis*, *E. lobulata*, *E. hispida*, *N. proboscidea vadescens* and *N. interrupta*. The last two neouvigerine species were investigated by comparing specimens having relatively smaller proloculi and larger ones.

Figure 36 shows the growth pathways of *E. akitaensis* complex, including subsp. *grandis*. Six representative specimens were obtained from four localities of which two contain the microspherics. These pair specimens are shown by the same symbols. All the examined specimens show a similar L/B pathway through ontogeny, execpt for the terminated test size. When plotting the length and breadth of a test as a function of the number of chambers, the developmental patterns of each specimen are clearly visible. The number of chambers of microspheric specimens is consistently three or four more, as compared with megalospheric ones of the same length from the same sample. Namely, the number of chambers is negatively correlated to prolocular diameter. The total test length does not show any relationship with prolocular dimorphism.

The prolocular diameter and chamber size of asexual specimens are changeable due to environments, and then the variation of test size results from these two flexible characters. At the same time, the prolocular diameters of sexual

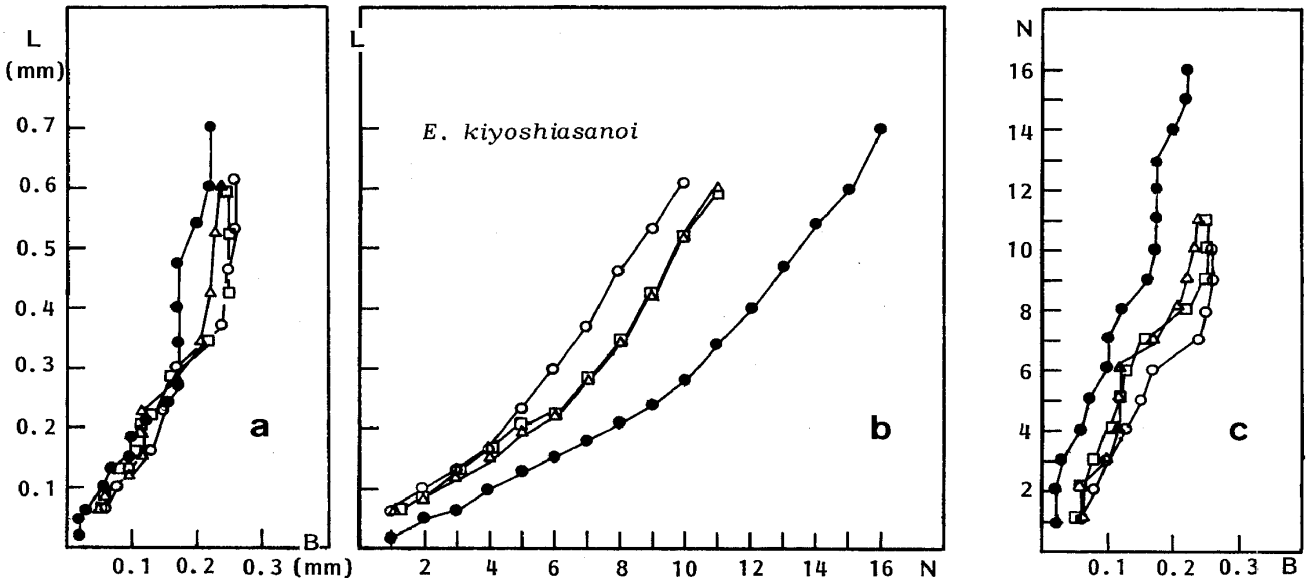


Fig. 37. Growth pathways of *E. kiyoshiasanoi*. Open symbol: megalospherics; solid symbol: microspherics. a: test breadth versus test length, b: number of chambers versus test length, c: test breadth versus number of chambers.

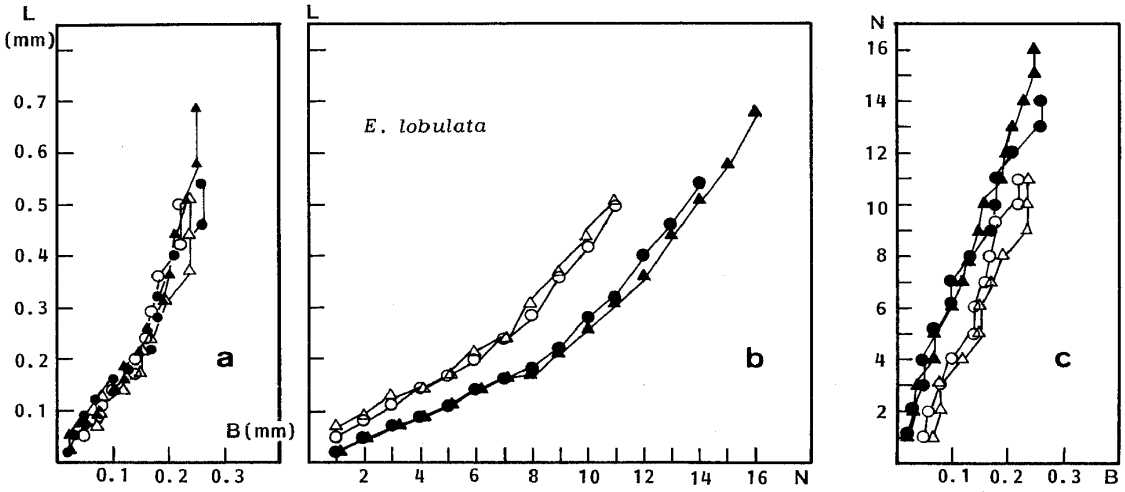


Fig. 38. Growth pathways of *E. lobulata*. Open symbol: megalospherics; solid symbol: microspherics. a: test breadth versus test length, b: number of chambers versus test length, c: test breadth versus number of chambers.

specimens are stable regardless of environments, but their chamber size is variable, as is the case of the megalospherics.

The growth pathways of the other five species were compared between the microspherics and megalospherics in a given population and are illustrated in Figs. 37-41.

E. kiyoshiasanoi, *E. lobulata* and *E. hispida* also show a distinct dimorphism in the number of chambers. Their chamber numbers of the microspherics are larger by three or four chambers than those of the megalospherics of the same length. Among these species *E. hispida*

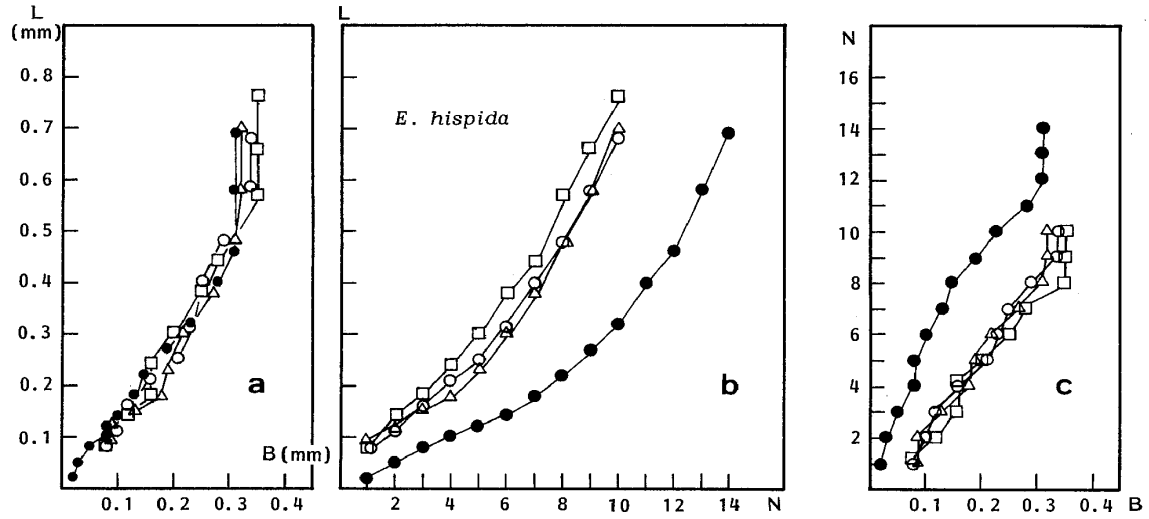


Fig. 39. Growth pathways of *E. hispida*. Open symbol: megalospherics; solid symbol: microspherics. a: test breadth versus test length, b: number of chambers versus test length, c: test breadth versus number of chambers.

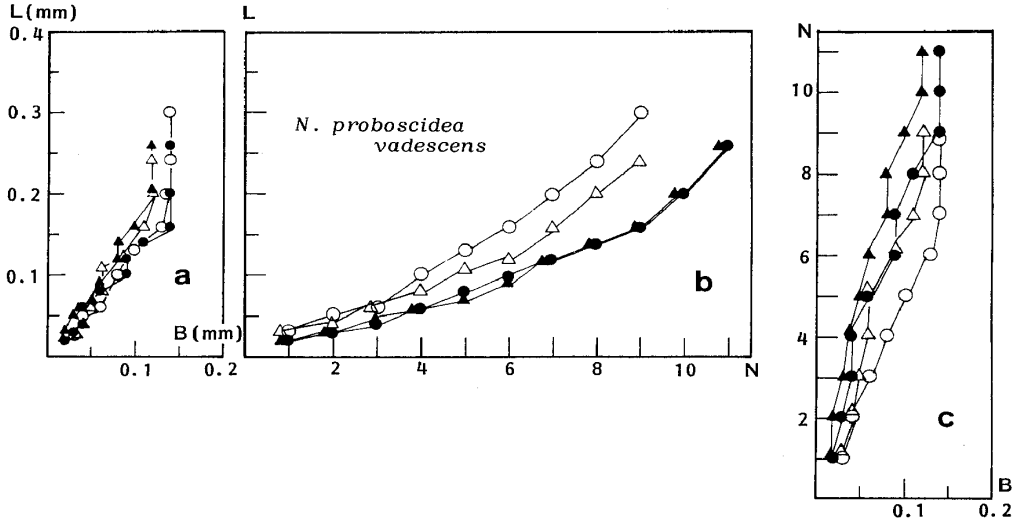


Fig. 40. Growth pathways of *N. proboscidea vadescens*. Open symbol: megalospherics; solid symbol: microspherics. a: test breadth versus test length, b: number of chambers versus test length, c: test breadth versus number of chambers.

is composed of relatively small numbers of chambers. Their difference is more distinct among sexual specimens.

All the examined euuvigerine species show a vivid dimorphism in the number of chambers which is negatively correlated with any prolocular size. Test length does, however, show no dimorphic differentia between sexual and asexual specimens.

As mentioned above, *N. proboscidea vadescens* and *N. interrupta* do not show any break in the frequency distribution of prolocular diameter. Then, two distinct groups are compared: one group is represented by specimens with proloculi of 20 μm and the other group, 30 μm. The number of chambers in

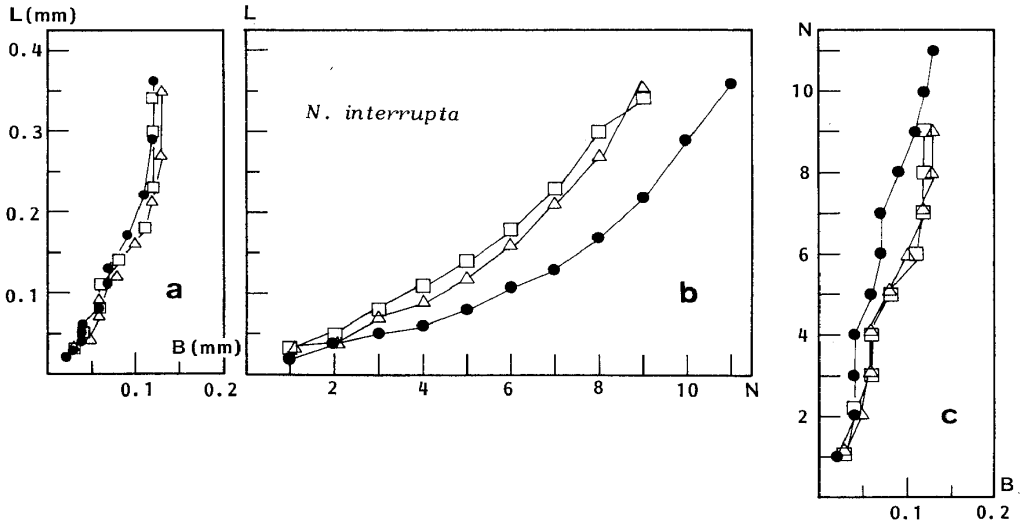


Fig. 41. Growth pathways of *N. interrupta*. Open symbol : megalospherics ; solid symbol : microspherics. a : test breadth versus test length, b : number of chambers versus test length, c : test breadth versus number of chambers.

these two species stands also in a negative relationship with prolocular size. Specimens having smaller proloculi are composed of eleven chambers, and those having larger proloculi consist of nine chambers. The number of chambers in the group with proloculi of 20 μm is smaller than that in the microspherics of euuvigerine species which possess 14 to 16 chambers in adult specimens. This difference is probably attributed to the fundamental characteristics of these two genera. Though *Neouvigerina* does not express a clear dimorphism in prolocular size, the smaller group possibly occurs with sexual reproduction.

Usually the test breadth of the microspherics at the fourth chamber stage is almost similar to the prolocular diameter of the megalospherics in euuvigerine species. In other words, dimorphism in the number of chambers is mainly subject to the initial difference in chamber number. This is also true in neouvigerine species.

5. Structure and Habitat Specialization

It has been well documented that ornaments of uvigerinids are strikingly correlated with environments (Bandy, 1960, 1966 ; Miller and Lohmann, 1982 ; Pflum and Frerichs, 1976 ; Van der Zwaan *et al.*, 1986). Uvigerinids can be separated into two major morpho-groups by their surface ornamentation, that is, spinose and costate groups. There are, however, diversified ornaments in-between, resulting from regulating the strength and combining patterns of ornaments.

The bathymetric distributions of eight selected species from the Kuroshio area are outlined in Figs. 42 and 43. Among these species four forms can be distinguished : costate, thickly costate-spinose, weakly costate-spinose and totally spinose. Thickly costate-spinose forms such as *E. aculeata*, *E. shiwoensis* and *E. curticosta* represent relatively shallower water inhabitants in the Kuroshio area. With increasing water depth, these thickly ornamented forms are replaced by *E. nipponica* whose ornaments are weak and combined with

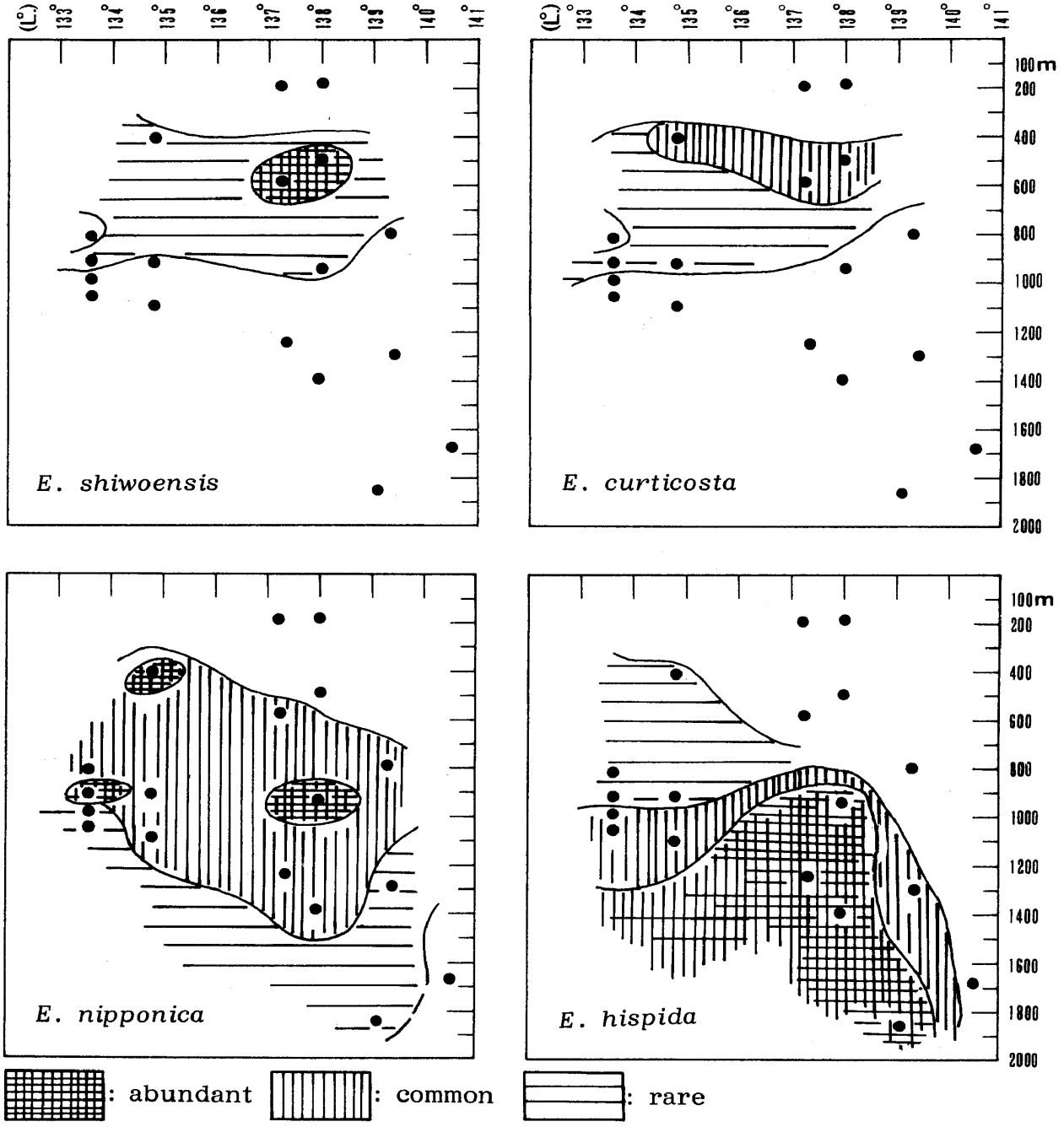


Fig. 42. Bathymetric and latitudinal distributions of *E. shiwoensis*, *E. curticosta*, *E. nipponica* and *E. hispida* in Kuroshio area.

costation and spinosity. The deepest inhabitant is represented by a totally spinose form, *E. hispida*.

The costate *Euuvigerina akitaensis* rarely occurs at the eastern side of this province and has its depth range from 400 to 1,200 m. The finely spinose *Neouvigerina interrupta* and *N. proboscidea vadescens* are distributed in the western part of this province. Their distributions do not overlap with that of the tansitional to subarctic *E. akitaensis*.

Examination of species occupying similar test size (test breadth) distribu-

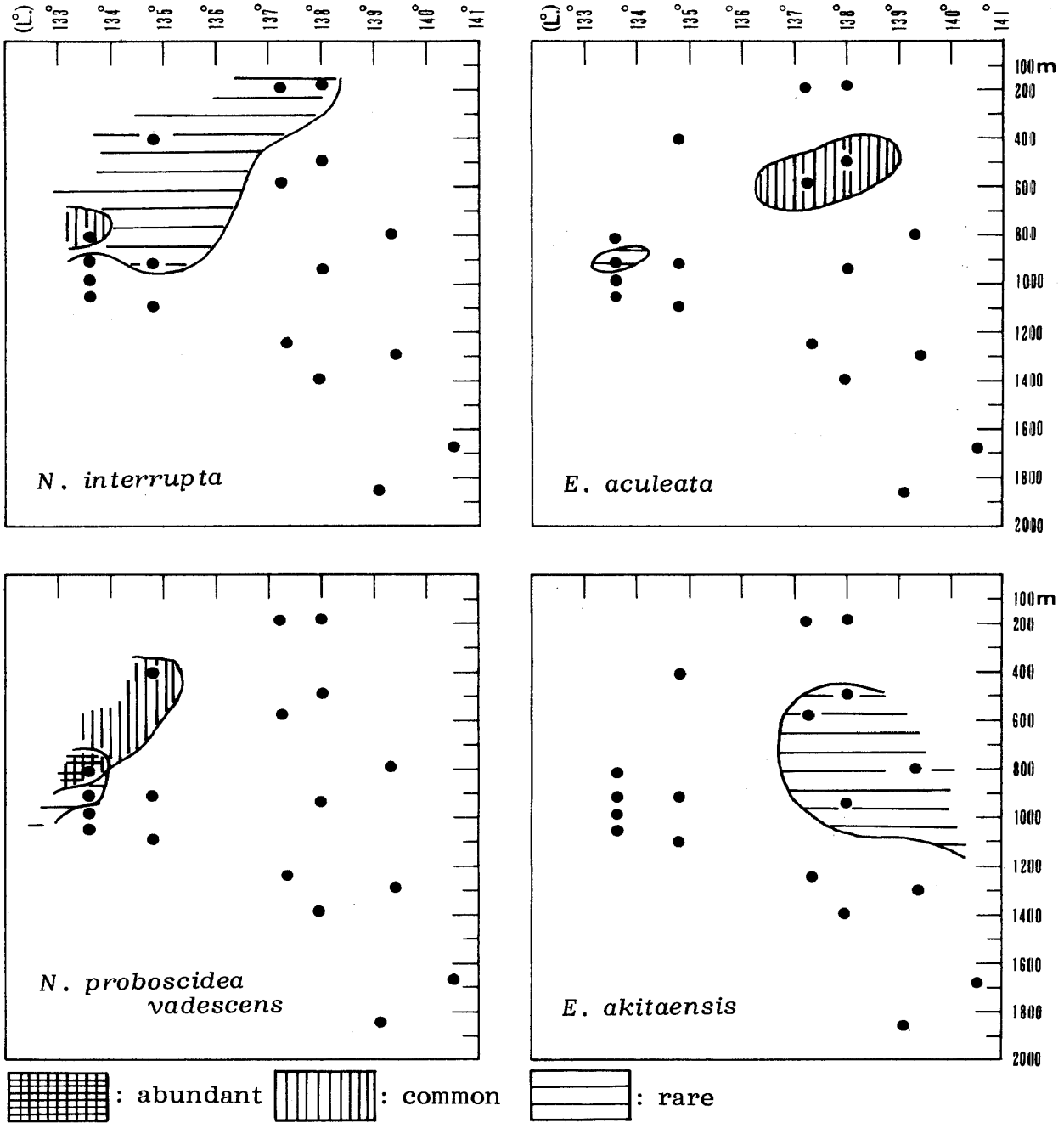


Fig. 43. Bathymetric and latitudinal distributions of *E. aculeata*, *E. akitaensis*, *N. interrupta* and *N. proboscidea vadescens* in Kuroshio area.

tions in relation to water depth shows clear relationships between surface ornaments and water depth. Figure 44 shows the size ratio (B/L) of six species from three samples of a traverse. With increasing water depth, the costate *E. akitaensis* and thickly costate-spinose *E. curticosta* are replaced by the weakly costate-spinose *E. nipponica*, entirely within a test breadth range of 0.25 to 0.35 mm. This replacement can be found in samples G-8 and G-2. Above 0.35 mm test breadth, a deeper water dwelling and totally spinose form, *E. hispida* is substituted for a shallower, thickly costate-spinose form, *E.*

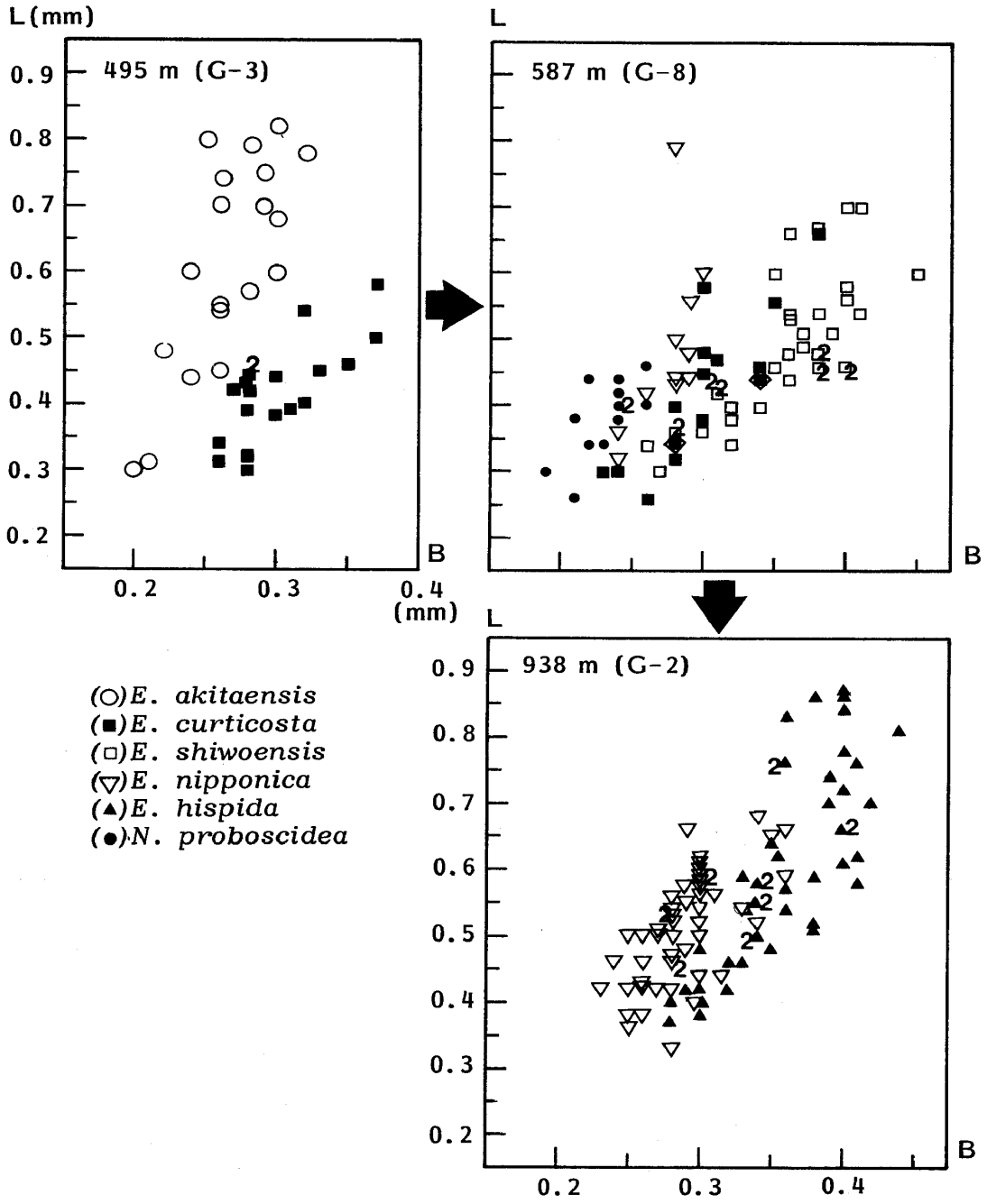


Fig. 44. Test size distributions of *E. akitaensis*, *E. curticosta*, *E. shiwoensis*, *E. nipponica*, *E. hispida* and *N. proboscidea* in three samples from Enshu-nada.

shiwoensis in sample G-2. *N. proboscidea* represents the smallest group.

In this way, the type of test ornaments or constituent species successively change with depth. Costate and thickly costate-spinose species are replaced by weakly costate-spinose species with increasing water depth, and then totally spinose species occupy deeper habitats.

In this province, two or more species of uvigerinids are usually sympatric. A complete partition in size distribution is also detected among coexisting congeners (Fig. 44). Such partitioning of test size implies that trophic resources are apportioned among coexisting uvigeri-

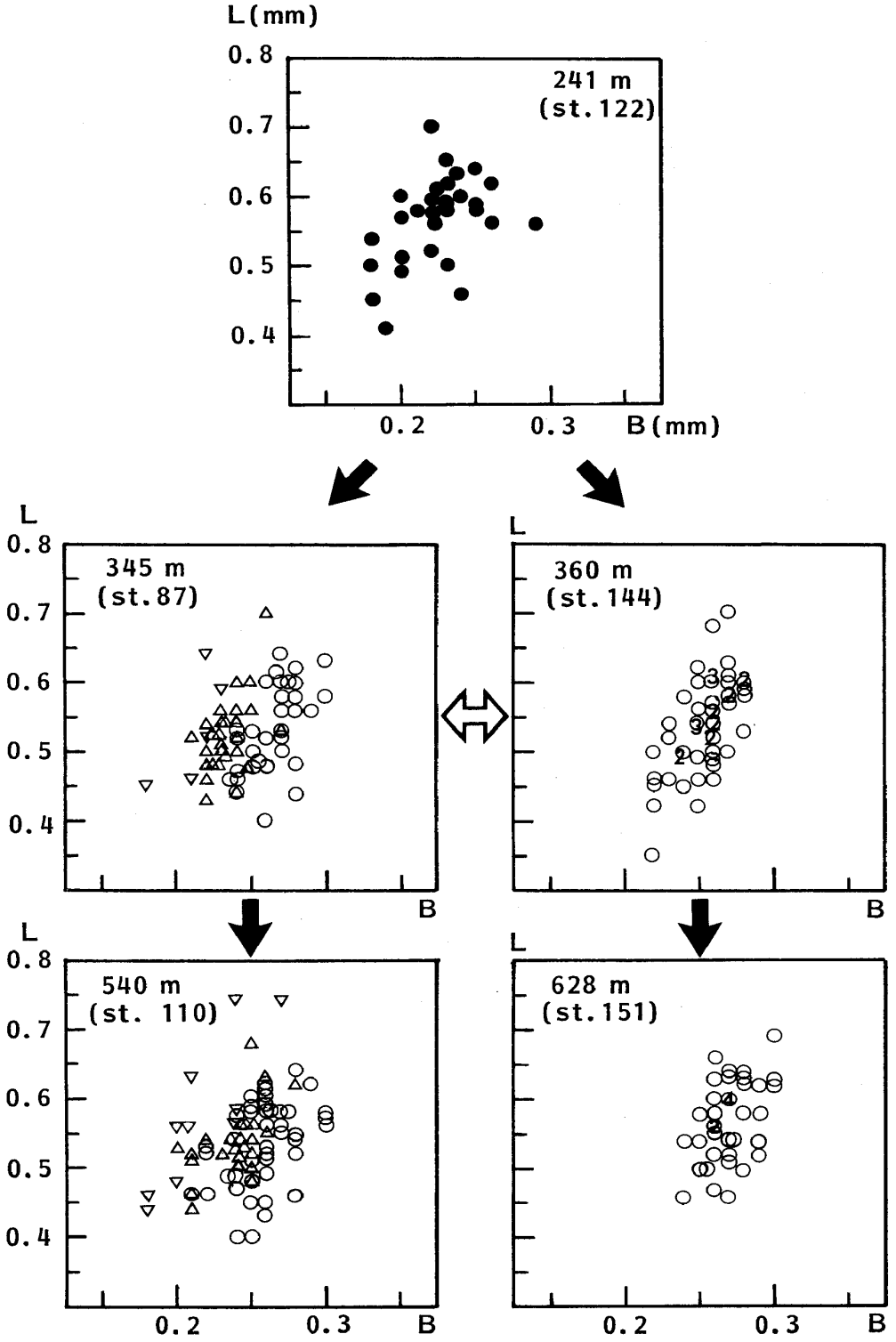


Fig. 45. Test size distributions of *E. kiyoshiasanoi* (solid circle), *E. lobulata* (triangle) and *E. akitaensis* (open circle) in five samples from Toyama Bay.

nids. This is a well known case in other animal groups (Hespenheide, 1973; Fenchel, 1975). The width of size distribution in a population is flexible with the number of coexisting congeners. For example, the *E. nipponica* population from sample G-8 occurs together with three other uvigerine species, and the width of size distribution is narrow and convergent, as compared with its sample G-2 counterpart which coexists with only one congener.

In that way, each of the coexisting uvigerinids shows a particular test size and species having a similar test size are differentiated by means of habitat specialization — for instance, separation of depth ranges.

A similar pattern was also detected in Toyama Bay. A shallower inhabitant is represented by the finely costate *E. kiyoshiasanoi* with intercostal pustules. This species ranges from 150 to 350 m, and is replaced by the prominently costate *E. akitaensis* and the spinose-costate *E. lobulata* with increasing water depth.

Figure 45 shows the size ratio (B/L) of the above three species from five samples. Usually, *E. kiyoshiasanoi* does not occur with other uvigerine species. The width of test size distribution of this species is relatively broad and scattered around 0.22 mm. *E. lobulata* often coexists with *E. akitaensis*, but differs from the latter in its test size distribution, being in a higher portion of L/B ratio. The boundary line between these two species is near a test breadth of 0.25 mm.

The test size of *E. akitaensis* changes with water depth and a coexisting congener. The deeper population has a larger test than the shallower one (compare st. 144 and st. 151). The population of *E. akitaensis* coexiting with *E. lobulata* performs the "character displacement" as defined by Brown and Wilson (1956). When populations of *E. akitaensis* from st. 87 and st. 144 are compared, the character displacement is detected in test breadth. A population from st. 87 has a broader test than that from sample st. 144. The above two samples are from almost the same water depth (345 and 360 m), and then, the factor of water depth can be excluded in consideration of the size variations. As mentioned above, *E. akitaensis* and *E. lobulata* usually occur sympatrically. These two closely related species may have a similar test size, when each of them exists alone at the same water depth. Populations of *E. lobulata* that occur allopatrically were not found in this investigation.

CONCLUDING REMARKS

From the present investigation on the wall microstructure and test morphology of the Japanese uvigerine foraminifera, the following facts were detected.

(1) The Japanese uvigerine forms can be classified by their toothplate formation into two genera, *Euuvigerina* and *Neouvigerina*. *Euuvigerina* has a simple plate-like toothplate which lies on the apertural lip of the former chamber. On the other hand, the toothplate of *Neouvigerina* is attached to the apertural neck or the outer border of a lip of the preceding aperture, but the shape of toothplates is various among species; three types recognized are the *N. setosa* type, *N. proboscidea* type and *N. interrupta* type. Toothplates are variable through ontogeny, but keep generic characters. This ontogenetic development is closely related to the successive change of coiling modes. The toothplate is no more than a folded part of the chamber wall.

(2) The test wall of *Euuvigerina* is composed of two types of crystal

elements, that is, morphologically radiate or fibrous crystal elements, and granular crystals. The radiate crystal elements are perpendicularly oriented to the test surface, bunched up in several crystal units and construct a main part of the test wall. The lamellae of granular calcites cover surfaces of the radiate layer by means of the inner and outer veneers. The wall structure of costae is fundamentally equal to non-ornamented parts, but the bearing of fibrous crystals is oblique to the latter, branching off the costal stem into chevron-like structures. Spines are formed with microgranular calcites, as indicated by the featureless nature of broken spines.

(3) *Euuvigerina* essentially has monolamellar characters, which are not consistent through ontogeny or among congeners.

(4) Perforate areas are more or less restricted and imperforate ones are developed on the following skeletal surfaces: the inner and outer surfaces of an apertural neck, toothplate and its adjacent portions, endoanulus, textural costae and spines. Imperforation of spines is essential and recognized throughout the wall section. The other imperforate areas are, however, due to thickly developed veneers.

(5) The number, shape and size of pores are variable through ontogeny and with environments. More elongate pores appear in the early portion of the test. Their elongation is related to the successively deposited lamellae of subsequently formed chambers. The intraspecific variations of shell porosity correspond with biogeographic provinces. Usually, specimens from the Japan Sea have a coarser pores and higher porosity than those from the Pacific Ocean off Japan. Each population has a distinct shell porosity value. Deeper water habitants have finer pores and lower porosity than shallower ones, and then ecologically equivalent forms have a similar shell porosity. Accordingly, shell porosity is a potential tool for identifying ecophenotypic variants rather than species.

(6) The variation of test size within a species is owing to that of chamber size. Deeper water populations have a larger test size than shallower ones.

(7) The terminal size is different among populations of a species, and each species has a peculiar growth pathway, or length and width development through ontogeny.

(8) Warm water species develop a more ovate test form and fewer chambers than cold water species in *Euuvigerina*. When counting the number of chambers as ages of foraminifera, it is suggested that warm water species more rapidly grow into adulthood than cold water ones. The number of chambers is uniform within a species, as compared between adult specimens.

(9) *Euuvigerina* shows a distinct dimorphism in prolocular size and the number of chambers. These two characters are negatively correlated to each other. At the same time, *Neouvigerina* does not show a bimodal distribution of prolocular size. Specimens with smaller proloculi have more numerous chambers than those with larger proloculi. However, no correlative relationship exists between prolocular dimorphism and test length. Generally, megalospheric specimens are much more abundant, as compared with microspheric specimens which are occasionally absent within a population. The reasons behind of these phenomena may be as follows: First, biflagellate gametes are very rare to conjugate with those from other parents — for example, most gametes weaken to be dead before conjugation. If environmental stresses are strong, the chance of conjugation will be progressively reduced. Second is holotrimorphism as seen in reproduction in

Ammonia beccarii. In this process gamonts produce microspheric schizonts which give rise to megalospheric schizonts by mitosis, not meiosis, which in turn produce megalospheric gamonts. Thirdly, reproduction is only performed by mitosis of megalospheric schizonts. It is noteworthy that the prolocular size of microspheric specimens is stable being 20 μm in all the examined species of *Euuvigerina*, but that of megalospheric specimens varies among species and also populations. The intraspecific variations of megalospheric proloculi are positively correlated with test size variations.

(10) Each species shows habitat specialization. Surface ornaments are progressively differentiated with increasing water depth, that is, shallower water dwelling and costate species are replaced by spino-costate species which are in turn pushed out by the deeper spinose ones.

(11) Size differentiation is distinct between coexisting congeners. The division of test size clusters implies partitioning of resources. And then, two morphotypes in the same size cluster can not exist sympatrically, being possible only when they have carried out a "character displacement" in size. Consequently, a displaced population differs from allopatrically existent populations in size.

CONCEPT OF TAXONOMY

1. General

Uvigerinid foraminifera can easily be distinguished by their terminated aperture with a siphonal neck or an inflated rim, and triserial to biserial coiling modes in the early stage. Since d'Orbigny described uvigerinid specimens in the name of *Uvigerina pygmea* in 1826, several morphological features have been examined, suggesting their validity for uvigerinid classification at the generic level. Hofker (1951) classified uvigerine foraminifera into three types based on characteristics of toothplates : *Euuvigerina* with a simple real toothplate, *Aluvigerina* with a dorsal wing on the toothplate, and *Neouvigerina* with a wing which is an atrophied toothplate. Vella (1961) acknowledged that toothplates have stable characteristics and are the most reliable taxonomic feature, but they are impracticale to fossil species. He also pointed out that toothplates have a consistent relationship with surface ornaments (sculpture) and test size. For this reason, he reclassified the uvigerine foraminifera into five genera. For example, forms having ribbon like ornamentation and becoming uniserial at the adult stage were separated as the genus *Hofkerva*. They, however, have the identical toothplate characteristic of Hofker's *Euuvigerina*. At the same time, it is well known that the ornaments are unsuitable criteria for the generic level taxonomy, owing to their variability with environments. Another character such as a coiling mode is applied for the subdivision of uvigerine tests. *Siphouvigerina*, proposed by Parr in 1950, was differentiated from *Uvigerina* by their uniserial development in the adult stage, which can be placed in Hofker's *Neouvigerina* in terms of toothplate characteristics. *Rectuvigerina* Mathews, 1945, and *Hopkinsina* Howe and Wallace, 1932, were also separated by their coiling modes (triserial to biserial and triserial to uniserial development, respectively). However, as indicated by Thomas (1980), ontogenetically altering characters of coiling type are not proper for distinguishing these genera, because

of difficulties in separating their juvenile specimens. Moreover, typical *Uvigerina* also occasionally shows one or more additional coiling types, which Boersma (1984) referred to stretched bi- or uniserial coiling. Mathews (1945) documented that the youthful stage of *Rectuvigerina* can easily be separated from wholly triserial *Uvigerina* by the presence of an internal tube (toothplate). As revealed by Hofker's study, however, all uvigerinid foraminifera have distinct toothplate characteristics. Loeblich and Tappan (1964) well consolidated many uvigerinid genera proposed by various workers until the 1950's. They carried out generic level separations based principally on a test form, chamber arrangement and apertural position and their modifications, including toothplates. Later, they (1984) ranked test forms up to the subfamily level criteria ; namely, triangular forms in the early stage were placed to the Angulogerininae Galloway, and rounded or uvigerine forms into the Uvigerininae Haeckel. It is interesting to note that they simultaneously employed several morphological features for generic taxonomy without assessing their relative importance ; some genera are based on coiling modes and others on toothplate characters. Since the criteria employed for generic separation were not clearly stated for some genera, comparison of those morphological features between genera is very difficult. Therefore, an immediate application of such criteria will cause confusion in some groups. For example, *Siphouvigerina* might be synonymous with *Rectuvigerina* in a broad sense, because the nature of toothplates in the latter has not been described, and coiling differences between them are not so great as to lead to generic distinction. All uvigerine forms with triserial to uniserial chamber arrangements may be assigned to the genus *Rectuvigerina* by some workers. If toothplate types have a very close relationship with the shape of chambers and their coiling modes, as indicated by Hofker (*op. cit.*), one can synthesize these two morphological features in a taxonomic framework for genera. Such possibilities are negated between *Uvigerina* (= Hofker's *Aluvigerina*) and *Euuvigerina*, because they have very similar coiling modes and chamber shapes and are only distinguishable by the nature of toothplates. In practical morphological taxonomy, external morphology is more easily observable and acceptable than the interior. Therefore, coiling modes are more practical criteria than internal toothplate characters. As stated above, however, coiling modes are also confronted with the problem caused by ontogenetic stages in several taxa. The present investigation led the writer to believe that toothplate characters are a more suitable and easy clue to generic separations. Though the pattern of toothplates also varies during ontogeny, this alteration is not over a generic character.

In this contribution, toothplate characteristics were accepted for generic taxonomy, and coiling modes were ranked down to the subgeneric level. Specimens having a secondary coiling type, confined to the final one whorl or so, were classified as a morpho-group of the primary coiling form. Besides these points, the uvigerine classification adopted at the generic level is mainly after the systematics organized by Loeblich and Tappan (1964). Finally, the following morphological features were considered significant in the recognition of morphotypes : in order of importance, 1) toothplate types, 2) coiling modes, 3) aperture and its modifications, 4) ornaments (spines, costae, pustules, etc.) and their combination patterns, 5) test size, and 6) size and shape of pores.

2. Species Concept

Traditional taxonomy is usually based on a typological species concept which does not include a full morpho-series of a species. Hence some morphotypes named as separate species by previous workers have been proved to be the end-members of other morphotypes. Occasionally, two distinct morphotyes have been indicated to be well-paired ecophenotypes, as extensively documented in several studies (Uchio, 1960 ; Lutze, 1964).

It is noteworthy that each of these bi- or polymorphotypes within a natural population usually has a particular geographical province. Sometimes the occurrences of these ecophenotypes are restricted within short stratigraphical intervals in a limited area. Therefore, the recognition of ecophenotypes is useful in paleoenvironmental reconstruction and indicating regional basin development. Further, an understanding of the variable morpho-parameters in a morphological scheme is very important for a proper taxonomy.

The classification of uvigerinid foraminifera at the specific level has mainly been attempted on the basis of surface ornamentation patterns. Unfortunately, ornamentation of uvigerinid tests is very flexible in correspondence with environmental cues. This phenomenon causes difficulties in the recognition of a natural population (species) through ordinary examination.

Many micropaleontologists who have studied local biostratigraphy and paleoenvironments separate the morphological groups with a very narrow range of variations and define their species. The term species seem to have been used for a representative morphotype in a certain district, like an ecophenotype. As a result, it is hard to compare and correlate between the regions widely separated, and their species names are occasionally valid only within a regional area. Nevertheless such morphotypes have been successfully applied for biostratigraphic zonations and paleoenvironmental analyses on local scale, irrespective of whether such "taxa" are genetically isolated.

The taxonomy followed in this contribution is essentially based on the assemblage species concept (Zachariasse, 1975 ; Van der Zwaan, 1982 ; Borsetti *et al.*, 1986 ; Van Leeuwen, 1986). The assemblage is defined as a successive morpho-group of specimens within a single sample, which shows the normal distribution and has morphological breaks between the adjacent morpho-groups. When intergradational specimens are found between distinct morphotypes from sample to sample, they were artificially assigned to a closer one in spatial-temporal distribution. If intermediate specimens have a distinct stratigraphic range and biogeographic province, they were also classified at the specific level. Each of forms is designated as a subspecies, when a marginal population has been proved to have constant and separable morpho-characteristics.

SYSTEMATIC DESCRIPTION

From a paleontological study of the uvigerine foraminifera occurred from Miocene to Recent materials from and around Japan, 29 morphotypes were distinguished, among which 19 come under *Euuvigerina* (s.s.), three *E.* (*Hopkinsina*) and seven *Neouvigerina*. They include six forms of *Euuvigerina* and two forms of *Neouvigerina*, described as new species or subspecies. In this chapter, all the 29 morphotypes are described. The systematic description of each morphotype is composed of several items : description, SEM observa-

tion, soft X-ray examination, type, remarks, distribution, stratigraphic range and etymology. "Description" shows a general feature of external morphology — for example, test forms and size, coiling mode, ornaments and apertural neck, etc. The size and shape of pores and toothplate characteristics are shown in "SEM observation", and prolocular size and the number of chambers in "soft X-ray examination". "Type" refer to holotype and/or paratype, and a full range of morphological variations, occurrence and coexisting species at the type locality are usually remarked. "Remarks" purport to help taxonomical work by contrasting the taxon to other similar species and give the information on the range of morphological variations. "Distribution" includes occurrences; sympatric occurrences are noticed on the basis of the result of this study. "Stratigraphic range" stands for an interval established by the first and last occurrences of the species in Japan, consulting previous studies on Japanese uvigerinids. All figured specimens are deposited in the Institute of Geology and Paleontology, Tohoku University, Sendai (Abbr. IGPS).

Suborder ROTALIINA Delage and Hérouard, 1896
Superfamily Buliminacea Jones, 1875
Family Uvigerinidae Haeckel, 1894
Subfamily Uvigerininae Haeckel, 1894
Genus *Euuvigerina* Thalmann, 1952
Euuvigerina aculeata (d'Orbigny), 1846

Pl. 33, fig. 8; Pl. 36, fig. 8; Pl. 44, figs. 6–10.

Uvigerina aculeata d'Orbigny, 1846, p. 191, pl. 11, figs. 27, 28; Brady, 1884, p. 578, pl. 74, figs. 1, 2; Asano, 1938, p. 613, pl. 17 (6), fig. 23; Asano, 1950, p. 14, figs. 58, 59; Asano, 1958, p. 33, pl. 6, figs. 3, 4.

Euuvigerina aculeata (d'Orbigny). Hofker, 1951, p. 226–231, figs. 150–152 (not figs. 153–154); Barker, 1960, p. 156, pl. 74, figs. 1, 2.

Description: Test elongate fusiform, large in size, about 0.75 to 1.2 mm in length, greatest breadth above middle portion, about 1.5 to 2 times as long as broad; coiling triserial; sutures distinct, depressed or contoured by successively formed chambers; chambers inflated, rapidly increasing in size; three morphotypes recognized from test ornamentation: perfectly spinose form throughout test length (Pl. 44, fig. 7), spino-costate form with spines developed in later portion (Pl. 44, fig. 6), and costate form with costae serrated deeply in later portion (Pl. 44, fig. 8); spines very stout, long and randomly distributed; costae thick, not continuous across sutures, forming marginal projections of chambers in earlier portion; a prominent, acicular spine usually develops in initial end; neck short, lacking ornament, terminated with a phialine lip.

SEM observation: 1) Pore: usually slit-like on early-formed chambers and circular on late ones; circular perforations about 0.95 μm in diameter (Pl. 33, fig. 8, Pl. 44, fig. 10). 2) Toothplate: euuvigerine type.

Soft X-ray examination: The microspherics, 20 μm in prolocular diameter and the megalospherics (A), about 100 μm; "A" forms usually composed of 8 to 9 chambers (Pl. 36, fig. 8).

Remarks: *Euuvigerina aculeata* resembles *E. shiwoensis* (Asano), but differs in its spinose surface ornamentation. Though a marginal morphotype of this species does not carry perfectly developed spines, it is also separable from *E. shiwoensis* by its more irregular, shorter and outward-stretching costae. This species is also similar to *E. hispida* (Schwager) and *E. curticosta* (Cushman), but is differentiated from *E. hispida* by its more stout spines and costae

developed in earlier portion, and from *E. curticosta* by its thicker ornamentation and an acicular spine at the initial end.
Distribution : *E. aculeata* is common to rare in Enshu-nada and Tosa Bay, with a depth range from 400 to 1,000 m. Its relative abundance is abruptly reduced below a water depth of approximately 600 m. This species often coexists with *E. shiwoensis* and *E. curticosta*. Asano (1950) reported that this species commonly occurred from the Pliocene Kiwada Formation of the Boso Peninsula. Only a few specimens were obtained from the Pliocene Iwasaka Formation of the peninsula in the present study.
Stratigraphic range : Pliocene to Recent.

Euuvigerina akitaensis (Asano), 1950

Pl. 25, figs. 1-3 ; Pl. 26, figs. 2-4, 6 ; Pl. 27, fig. 2 ; Pl. 33, figs. 1, 2, 4, 9, 12 ; Pl. 36, figs. 1-5 ; Pl. 41, figs. 5-10.

Uvigerina akitaensis Asano, 1950, p. 14, figs. 60-62 ; Ishiwada, 1950, fig. 20 ; Asano, 1958, p. 33-34, pl. 6, figs. 9-11 (not figs. 12-13) ; Chiji, 1959, p. 24-25, pl. 7, fig. 1 ; Kikuchi, 1964, pl. 1, figs. 1-8 ; Aoki, 1965, p. 53, pl. 7, figs. 16-17 ; Matoba, 1967, p. 257, pl. 26, figs. 4-6 ; Keller, 1977, pl. 4, figs. 9-10.
Uvigerina asanoi Matsunaga, 1963, p. 113, pl. 42, figs. 10a, b.
Uvigerina cf. *bifurcata* d'Orbigny. Asano, 1938, p. 77-78, pl. 17(6), figs. 3-4 ; Ishiwada, 1950, fig. 9.
Uvigerina excellens Todd. Matsunaga, 1963, pl. 42, figs. 11a, b.
Uvigerina nitidula Schwager. Matsunaga, 1963, pl. 42, figs. 12a, b.
Uvigerina pygmea d'Orbigny. Brady, 1884, p. 575, pl. 74, figs. 13, 14 (not figs. 11, 12).
Uvigerina yabei Asano. Keller, 1977, pl. 4, figs. 11-12.
Uvigerina sp. Keller, 1977, pl. 4, fig. 13.
Euuvigerina cf. *yabei* (Asano). Takayanagi and Hasegawa, 1986, pl. 1, fig. 6.

Description : Test elongate, medium in size, usually 0.5 to 0.8 mm in length, subcylindrical, greatest breadth above middle portion, about 2.5 to 3 times as long as broad ; coiling triserial, rarely biserial in full adult specimens ; periphery lobulated ; sutures distinct, depressed ; chambers slightly inflated ; chamber gradually increase in size ; test ornamented with well spaced, more or less thin, high, sharply edged costae ; costae about 8 in a chamber, independent of those of adjacent chambers, sometimes weakened or serrated on ultimate chamber ; apertural neck relatively short, smooth, with a phialine lip.
SEM observation : 1) Pore : circular to ovate, 0.5 to 2.0 μm in maxium diameter (Pl. 33, figs. 1, 2, 4, 9, 12 ; Pl. 41, fig. 7). 2) Toothplate : euuvigerine type.
Soft X-ray examination : The microspherics (B), 20 μm in prolocular diameter while the megalospherics (A) about 50 to 120 μm (clustered in 60 to 80 μm) ; the adult specimens of "A" form usually composed of about 12 chambers in contrast to about 15 ones in "B" form of a size (Pl. 36, figs. 1-5).
Remarks : *E. akitaensis* resembles *E. yabei* (Asano), but differs from the latter in its thinner, higher and more sharply edged costae. Matsunaga (1963) proposed *Uvigerina asanoi* and distinguished it from *E. akitaensis* in having slightly serrated costae in the final chamber. This morphotype is frequently found in association with the typical *E. akitaensis*, constituting the marginal morpho-group of *E. akitaensis*, but any discrete boundaries can not be drawn in between. For this reason, *U. asanoi* is included into the synonymy of the latter. This species is very variable in test size. Through examination of approximately two thousand specimens, including Asano's collections, from several localities, it is recognized that each geographic province has a peculiar distribution of test size. For example, specimens distributed in the Japan Sea are smaller than those in the Transition and Oyashio areas in the N.W. Pacific.

Two marginal populations are

differentiated into subspecies, that is, subsp. *grandis* which has a large test and subsp. *pumila*, a small test. They never occur in association with the typical form, and those two and the typical forms show discrete distributions in test size.

Distribution: *E. akitaensis* is commonly found from the uppermost part of Late Miocene Uchisugawa Formation, the Pliocene Kuwae, Sawane, Yabuta Formations and the Pleistocene Kitaura and Wakimoto Formations distributed along the Japan Sea side. On the Pacific side, the Pliocene Umegase and Iioka Formations yield commonly this species. The species is usually found in association with *Cassidulina norvangi* Thalmann, *Islandiella norcrossi* (Cushman) and *Epistominella pulchella* Husezima and Maruhasi in the strata on the Japan Sea side, and with *Bulimina aculeata* d'Orbigny in those of the Pacific side. It is also common in both the Japan Sea and N.W. Pacific. *E. akitaensis* shows different bathymetric ranges in the two regions, namely, from 250 to 1,000 m in the former and from 800 to 2,000 m in the latter, and occurs most commonly at depths of about 400 m and 1,500 m, respectively. It is, however, quite few in the warm Kuroshio region.

Stratigraphic range: Late Miocene to Recent.

Euuvigerina akitaensis (Asano) *grandis* Jung, n. subsp.

Pl. 26, fig. 5; Pl. 27, fig. 1; Pl. 28, figs. 1-8; Pl. 36, figs. 6-7; Pl. 41, figs. 1-4.

Description: This subspecies is separated from typical form in its larger test and chamber size; test length up to 1.36 mm, test breadth clustered within the range from 0.35 to 0.40 mm.

SEM observation: 1) Pore: subcircular to slightly ovate, ranging from 1.0 to 1.8 μm in maximum diameter, about 13 pores per $15\times11\ \mu m^2$ square. 2) Toothplate: euuvigerine type, thinner and narrower, as compared with *E. shiwoensis* (Asano) (Pl. 28, figs. 1-8.) 3) Crystal units: distinct, mosaic shape (Pl. 41, fig. 3).

Soft X-ray examination: The megalospherics range from 70 to 130 μm (clustered at 80 to 100 μm) in prolocular diameter and their adult tests are composed of about 12 chambers in contrast with 15 to 16 chambers in the microspheric specimens with a 20 μm-diameter proloculus (Pl. 36, figs. 6-7).

Holotype: IGPS 99774, Pl. 41, fig. 1 (OB22-U) from the horizon one meter above the key tuff bed Oz 5, Kitaura Formation; a sea cliff 570 m west of Oibanazaki, Oga Peninsula, Akita Prefecture.

Remarks: This subspecies resembles *E. yabei* (Asano) in its large test size, but keeps the characteristics of *E. akitaensis* in its sharply edged costation; the latter shows more smooth costation. This subspecies is differentiated from the typical form in its discrete distribution of test size.

Distribution: This subspecies abundantly occurs from the Pleistocene Kitaura Formation outcropping at the sea cliff west of Oibanazaki, Oga Peninsula. Its stratigraphic distribution is very restricted within an interval of 95 m between key tuff bed Oz 5 and the horizon 25 m above key bed Oz 1 at the above mentioned locality. There are serveral interbedded ooze beds (0.2 to 1 cm thick) of planktonic foraminifera; the ratio of the planktonics to the total number of foraminifera exceeds more than 90% in the examined samples. These facts reflect that this subspecies inhabited more poorly oxygenated environments than did the typical *E. akitaensis*. At the same time the associated species with subsp. *grandis* are identical with those with the typical form on the Japan Sea side, that is,

Cassidulina norvangi, *Islandiella norcrossi*, *Epistominella pulchella*, and others.
Stratigraphic range: Pleistocene.
Etymology: This subspecies is named from the Latin adjective *grandis*, grand.

Euuvigerina akitaensis (Asano) *pumila* Jung, n. subsp.

Pl. 41, figs. 11-13.

Uvigerina sp. A Aoki, 1965, p. 53, pl. 7, fig. 18.
Uvigerina akitaensis Asano. Matoba and Honma, 1986, pl. 4, figs. 7a, b.

Description: This subspecies is differentiated from typical form in its smaller and much slender test; test dimensions clustered around 0.46 mm in length and around 0.20 mm in breadth.
SEM observation: 1) Pore: circular, 0.45 to 0.75 μm in diameter, about 17 pores per 15×11 μm^2 square (Pl. 41, fig. 13). 2) Toothplate: euuvigerine type.
Holotype: IGPS 99776, Pl. 41, fig. 11 (BS 8602208); 7 m below key tuff bed U2, Umegase Formation outcropping at river side of Yoro-gawa, 300 m north of Imohara, Ichihara City, Boso Peninsula, Chiba Prefecture.
Remarks: This subspecies is easily separable from the typical form in its smaller test size and much slender shape. Aoki (1965) first recognized this form and separated it from the typical *E. akitaensis* as variety A.
Distribution: This subspecies rarely occurs from the uppermost part of the Pleistocene Umegase Formation distributed in the Boso Peninsula. Aoki (*op. cit.*) reported that it is sporadic in the Jizodo, Yabu, and Semata Formations and very rare in the Narita Formation. He remarked that this form differs from the typical in habitat, and lives in the middle shelf zone.
Stratigraphic range: Pleistocene to Recent.
Etymology: This subspecies is named from the Latin adjective *pumilus*, small and dwarfish.

Euuvigerina curticosta (Cushman), 1927

Pl. 36, figs. 13, 14; Pl. 45, figs. 7-12.

Uvigerina pigmea d'Orbigny var. *curticosta* Cushman, 1927, p. 157, pl. 4, fig. 1.
Uvigerina peregrina Cushman var. *curticosta* (Cushman). Todd, 1948, p. 266, pl. 34, figs. 2a, b.
Uvigerina curticosta Cushman. Uchio, 1960, p. 65, pl. 7, figs. 12, 13.
Uvigerina peregrina Cushman var. *dirupta* Todd, 1948, p. 267, pl. 34, figs. 3a-c; LeRoy, 1964, p. 34, pl. 4, fig. 4.
Uvigerina peregrina dirupta Todd. Kikuchi, 1964, pl. 1, figs. 13-15.

Description: Test elongate fusiform, medium-sized for the genus, 0.50 to 0.80 mm in length; greatest breadth at or above middle portion, about twice as long as broad; coiling triserial, but becomes biserial in later one-third of test length; chambers in earlier to middle portion rather compact, making sutures obscure by costal margins in some cases, especially in earlier portion, but ultimate chamber inflated; sutures depressed; chambers increasing rapidly in size in early portion; test ornamented with relatively thick, sharp and high costae in earlier and middle portions, and developed into serrated or spinose in ultimate chamber; costae relatively winding, curved and overhung along sutural lines, but not continuous across sutures, widely-spaced intercostal trough sometimes occupied with rows of minute spines; spines fully developed in final chamber; spinose ornament continuing to apertural neck, except uppermost part of neck; neck stout, medium in length and terminated by phialine lip.
SEM observation: 1) Pore: circular, about 0.5 μm in diameter; 26 pores per 15×11 μm^2 square. 2) Toothplate: euuvigerine type.
Soft X-ray examination: Microspheric specimens are easily differentiated from

megalospheric ones on the basis of prolocular size in the same sample. Prolocular diameters of the microspherics and megalospherics are about 20 μm and 80 μm, respectively (Pl. 36, figs. 13-14).

Remarks: *E. curticosta* resembles *E. nipponica* Jung, n. sp. in its spino-costate ornamentation, but differs from the latter in its larger test size and relatively curved costae which are higher, sharper and more broadly spaced. Moreover, it is characterized by a stouter and shorter neck. This species also resembles *E. hispidocostata* (Cushman and Todd) described from Jamaica, but differs in its much stronger test ornaments than the latter.

Distribution: *E. curticosta* commonly occurs from Recent sediments in the Kuroshio area, at depths ranging from 300 to 1,000 m. Its tests are relatively small as compared with the typical ones.

E. curticosta also occurs commonly in the Pliocene Yonabaru Formation, Okinawa and rarely in the Late Miocene Aya Member of Higashimorogata Formation, Miyazaki. The specimens from Okinawa are larger than those from other localities in and around Japan. This large group is referable to *Uvigerina peregrina* var. *dirupta* Todd which is within the range of variations of *E. curticosta*.

Stratigraphic range: Late Miocene to Recent.

Euuvigerina flintii (Cushman), 1923

Pl. 31, fig. 4; Pl. 36, fig. 10; Pl. 48, figs. 6-10.

Uvigerina flintii Cushman, 1923, p. 104, pl. 42, fig. 13; Borsetti *et al.*, 1986, p. 210, pl. 8, figs. 1-3.

Description: Test elongate fusiform, comparatively small in size, about 0.4 mm in length; greatest breadth at middle portion, about 1.5 times as long as broad; coiling triserial throughout; chambers inflated; sutures depressed, but obscured by numerous costae; costae fine, narrowly spaced, rounded at edge, well developed in middle portion, but become weakened toward apertural end, some individuals with smooth appearance at final chamber; costae covering up sutures, sometimes fused with those of adjacent chambers; apertural neck standing in a depressed base, surrounded with one or two ring-like projections and terminated with a phialine lip.

SEM observation: 1) Pore: subcircular, about 0.4 μm in diameter (Pl. 48, fig. 10). 2) Toothplate: euuvigerine type (Pl. 31, fig. 4).

Soft X-ray examination: The megalospherics are about 60 μm in prolocular diameter. No microspherics are found in the examined material (Pl. 36, fig. 10).

Remarks: Japanese Pliocene specimens slightly differ from the typical specimen described from off Carysfort Light, Florida, U.S.A., in having rather thicker costae. They keep, however, the characteristics of *E. flintii* with numerous costae and ring-like projections of an apertural neck.

Distribution: *E. flintii* is very rare in the Pliocene Yonabaru Formation distributed in Okinawa Island.

Stratigraphic range: Pliocene.

Euuvigerina hispida (Schwager), 1866

Pl. 31, figs. 7-9; Pl. 35, figs. 11-12; Pl. 47, figs. 1-9.

Uvigerina hispida Schwager, 1866, p. 249, pl. 7, fig. 95; Cushman, 1929, p. 95, pl. 13, fig. 35; LeRoy, 1941a, p. 36, pl. 1, figs. 102, 103; LeRoy, 1941b, p. 82, pl. 2, fig. 15; LeRoy, 1964, p. 34, pl. 4, figs. 2, 3; Pflum and Frerichs, 1976, pl. 8, figs. 9, 10 (not fig. 8); Borsma, 1984, p. 74, figs. 1-4; Van Leeuwen, 1986, p. 64, pl. 3, figs. 1-3.

Euuvigerina hispida (Schwager). Srinivasan and Sharma, 1980, p. 48, 49, pl. 7, figs. 14, 15.

Description: Test elongate fusiform, large in size, up to 0.9 mm in length; greatest breadth at or above middle

portion, from 2 to 2.5 times as long as broad; coiling triserial in earlier portion, bi- to uniserial in late portion; sutures distinct, deeply incised; chambers strongly inflated, rapidly increasing in size, some individuals having a bluntly round initial end; test covered with numerous spines, which are randomly distributed in usual, but rarely aligned longitudinally; spines high, sharply pointed, but become shortened in fossil specimens; spinose ornament continue to apertural neck, except for uppermost part of neck; apertural neck cylindrical, slender, relatively long and terminated with a phialine lip.

SEM observation: 1) Pore: circular, about 0.4 μm in diameter, about 17 pores per 15×11 μm^2 squre (Pl. 47, fig. 6). 2) Toothplate: euuvigerine type (Pl. 31, figs. 7-9). 3) Spine: broken spines show well-developed lamellarity (Pl. 47, fig. 9).

Soft X-ray examination: The microspherics composed of about 14 chambers, 20 μm in prolocular diameter, and the megalospherics, about 10 chambers, prolocular diameter ranging from 80 to 90 μm (Pl. 35, figs. 11, 12).

Remarks: *E. hispida* has a wide range of variations in the length and distribution pattern of spines. The typical morphotype of this species has randomly distributed spines. On the contrary, the marginal morpho-group develops spines aligned longitudinally (Pl. 47, fig. 4), and such spines are never fused with each other. In this respect it is not so hard to separate this marginal morpho-group from such related species as *E. curticosta* (Cushman) (*dirupta* type) and *E. nipponica* Jung, n. sp., of which ornaments are combined with spinosity and costation. Furthermore, *E. nipponica* is more easily separable from *E. hispida* in its weak ornamentation. The variation of spine length is mainly due to such post-mortem effects as breaking and/or dissolution. Such affected specimens may assume fairely different appearances, but keep a hispid form and large test size.

Distribution: *E. hispida* is widely distributed in the Kuroshio area including Enshu-nada, Kii-suido and Tosa Bay. It bathymetrically ranges from 400 to 2,000 m, but commonly occurs at depths below 1,000 m. This species frequently coexists with *E. curticosta* in the upper part of the depth range, and with *E. nipponica* Jung in the lower part. Fossil specimens are very rare, but found from the Pliocene Yonabaru Formation in Okinawa, Yonahama Formation in Miyakojima, and the Late Miocene Aya Member of Higashimorogata Formation in Miyazaki Prefecture.

Stratigraphic range: Late Miocene to Recent.

Euuvigerina hispidocostata (Cushman and Todd)

Pl. 33, fig. 7; Pl. 36. fig. 9; Pl. 46, figs. 8-11.

Uvigerina hispido-costata Cushman and Todd, 1945, p. 51, pl. 7, figs. 27, 31; Phleger and Parker, 1951, p. 18, pl. 8, figs. 17-19; Parker, 1954, p. 520, pl. 8, fig. 3; LeRoy, 1964, p. 35, pl. 16, fig. 7; Borsma, 1984, p. 77-81, figs. 1-4.

Description: Test elongate fusiform, medium in size ranging from 0.6 to 0.8 mm in length; greatest breadth at above middle portion, about 1.5 to 2 times as long as broad; coiling triserial in earlier portion, becoming biserial in last one or two chambers; chambers inflated, gradually increasing in size; initial end bluntly pointed; periphery lobulate in middle portion; sutures slightly incised; test ornamented with sharp, longitudinal and relatively high costae, about 10 to 15 costae per chamber in middle portion, costae discontinuous across sutures, transforming into rows of spines toward apertural end; intercostal area ornamented with minute spines and pustules, especially in middle portion; apertural neck medium in length,

terminated with a phialine lip.

SEM observation: 1) Pore: circular to subcircular in ultimate chamber, 0.35 to 0.5 μm in maximum diameter, slit-like openings at earlier portion (Pl. 46, fig. 11, Pl. 33, fig. 7). 2) Toothplate: euuvigerine type.

Soft X-ray examination: Diameters of proloculi from 80 to 100 μm in the megalospherics (Pl. 36, fig. 9) and 20 μm in the microspherics.

Remarks: *E. hispidocostata* is very variable in its ornaments, as expressed by its species name. Some individuals are very similar to *E. curticosta* (Cushman) and the marginal morphogroup of *E. hispida* (Schwager) with rows of spines. In the present work, *E. hispidocostata* is classified as a morphotype having relatively numerous longitudinal costae in earlier and middle portions, and spines developed at the apertural end. It is separated from *E. hispida* by costal features and from *E. curticosta* by its rather weaker costae. *E. hispidocostata* does not coexist with *E. nipponica* Jung, n. sp. and is distinguished from the latter in having larger tests with higher and thicker costae.

Distribution: *E. hispidocostata* is not found in Recent sediments around Japan, but rarely occurs from the Yonabaru Formation in Okinawa and the Yonahama Formation in Miyako-jima. These formations are assigned to the Pliocene.

This species shows a morpho-series through ontogeny. The juvenile individuals are ornamented with costae throughout the whole length and the adult ones develop spinose ornaments in the later portion.

Stratigraphic range: Pliocene.

Euuvigerina introrsa Jung, n. sp.

Pl. 31, fig. 5; Pl. 35, figs. 5, 10; Pl. 46, figs. 1-7.

Description: Test elongate fusiform, medium in size for the genus, 0.50 to 0.75 mm in length; greatest breadth at or above middle portion, 1.3 to 1.9 times as long as broad; coiling triserial throughout; sutures distinct, contoured by succeeding chambers or simply depressed; chambers strongly inflated, rapidly increasing in size toward maximum test breadth; test ornamented with numerous, thin, high, sharply edged costae, about 15 costae per chamber, costae interrupted by sutures, introrsely curved toward sutural depressions, usually costae forming introrse overhangs along sutural lines; these overhangs develop to marginal projections of chambers in initial, sometimes intercostal troughs of last-formed chambers occupied with spines; costae do not continue to apertural neck; apertural neck short, usually surrounded with spinose projection, terminated with a phialine lip.

SEM observation: 1) Pore: subcircular, about 0.53 μm in maximum diameter (Pl. 46, fig. 6). 2) Toothplate: euuvigerine type (Pl. 31, fig. 5).

Soft X-ray examination: Microspheric specimens about 30 μm in prolocular diameter, megalospherics about 90 μm (Pl. 35, fig. 10).

Holotype: IGPS 99791, Pl. 46, fig. 1 (OM-13) from the Pliocene Takanabe Member of the Koyu Formation, outcropping at Sakamoto, Takanabe-cho, Koyu-gun, Miyazaki Prefecture. This species rarely occurs there and coexists with *Euuvigerina curticosta* (Cushman).

Remarks: *Euuvigerina introrsa* resembles *E. nitidula* (Schwager), but differs in its more numerous, high, narrowly-spaced costae, more stout apertural neck and marginal projections at the initial end. This species also resembles *E.*

hispidocostata (Cushman and Todd), but differs in its fully-developed costae throughout the test length, short apertural neck and spinose projections at the initial end.

Distribution: This species rarely occurs in the Pliocene Takanabe Member of the Koyu Formation distributed in Miyazaki Prefecture and the Pliocene Yonahama and Shinzato Formations outcropping in Okinawa Island. This species often coexists with *E. curticosta* in Miyazaki, with *Neouvigerina auberiana ampullacea* (Brady) and *E. hispidocostata* in Okinawa Island. Its large specimens are commonly found in the middle part of the Pliocene Yonahama Formation in Miyako-jima. This species also rarely occurs in Recent sediments (TS-7) from Tosa Bay (water depth approximately 918 m). In this sample, relatively small specimens of *E. introrsa* sympatrically occur with numerous specimens of *E. nipponica* Jung, n. sp.

Stratigraphic range: Pliocene to Recent.

Etymology: The specific name *introrsa* is derived from the Latin adjective *introrsus*.

Euuvigerina juncea (Cushman and Todd), 1941

Pl. 27, figs. 3, 5, 6; Pl. 30, figs. 1, 4-7; Pl. 33, figs. 3, 11; Pl. 40, figs. 1-5.

Uvigerina juncea Cushman and Todd, 1941b, p. 78, pl. 20, figs. 4-11.

Uvigerina tenuistriata Reuss. Brady, 1884, p. 574, pl. 74, figs. 4-7.

Uvigerina cushmani Todd, 1948, p. 257-258, pl. 33, figs. 1a-g; Barker, 1960, p. 154, pl. 33, figs. 4-7.

Uvigerina cf. *yabei* Asano. Aoki, 1965, p. 58, pl. 7, figs. 20, 21, (?)27.

Description: Test elongate, medium in size, 0.56 to 0.80 mm in length, rounded in lateral section; greatest breadth above middle portion, about three times as long as broad in fully-developed specimens; coiling triserial up to bi- to uniserial with one or two last-formed chambers; chambers rapidly increasing in size, slightly inflated; sutures distinct, gently curved; test ornamented with numerous widely-spaced, thin, low, and weak costae; costae best developed in middle portion and weakened toward apertural end — smooth on ultimate chamber, and not continuous across sutures — in rare cases, fused with adjacent ones at sutural depressions; ultimate chamber deeply concave inward, bipartite by a line of depression; apertural neck short, terminated with a slightly reverted lip.

SEM observation: 1) Pore: circular, about 0.78 μm in surface opening diameter, situated at center of crystal units such that one perforation at each unit in general, or sometimes two units fused into a larger unit. 2) Toothplate: initiated on lip of preceding aperture, continued to apertural neck, changing its plane at an angle of approximately 120 degrees near its apertural base.

Remarks: This species closely resembles *E. yabei* (Asano), but differs in its thinner, more numerous costae and smaller test size than in the latter. Though Asano (1950) mentioned that *Uvigerina cushmani* Todd (synonymous with *E. juncea* in this paper) is a variant of *E. yabei*, the thin and numerous costae of *E. juncea* are so distinct that it may be properly classified at the specific level. In addition, these two species have different geographic distributions in Japan; in land sections, *E. juncea* is distributed along the Pacific coast, on the other hand, *E. yabei* on the Japan Sea side.

Distribution: *E. juncea* is commonly distributed in the lower part of the Pleistocene Chonan Formation, Boso Peninsula.

Stratigraphic range: Pleistocene.

Euuvigerina kiyoshiasanoi
Jung, n. sp.

Pl. 27, fig. 4 ; Pl. 30, fig. 2 ; Pl. 33, fig. 6 ; Pl. 35, figs. 3, 4 ; Pl. 40, figs. 6–11.

Uvigerina akitaensis Asano. Hasegawa, 1979, pl. 4, figs. 8a, b.
Uvigerina juncea Cushman and Todd. Keller, 1977, pl. 5, figs. 3–5.
Uvigerina subperegrina Cushman and Kleinpell. Chiji, 1959, p. 28, pl. 7, figs. 7–8.

Description : Test elongate fusiform, medium in size, 0.4 to 0.7 mm (most are 0.5 to 0.6 mm) in length ; greatest breadth at middle portion, about 2.5 times as long as broad ; coiling mostly triserial throughout, but rarely bi- to uniserial in later stage ; chamber size rapidly increasing in earlier portion ; chambers inflated ; sutures distinctly incised ; test ornamented with widely-spaced, thin, sharply edged costae which are cut by sutural lines in general ; costae best developed in middle portion and serrated toward apertural end ; intercostal trough occupied with numerous pustules ; in some specimens costae weakened in later portion where intercostal trough studded with much more pustules ; apertural neck relatively short, terminated with a distinct phialine lip.

SEM observation : 1) Pore : circular, surrounded with inflated inter-pore area at ultimate chamber (Pl. 33, fig. 6), ovate at antepenultimate chamber (Pl. 40, fig. 11). 2) Toothplate : euuvigerine type (Pl. 30, fig. 2).

Soft X-ray examination : Test composed of 10 to 15 chambers. Microspherics about 20 μm in prolocular diameters, but megalospherics about 60 μm (Pl. 35, figs. 3, 4).

Holotype : IGPS 99801, Pl. 40, fig. 8 (KT85-15, G-1 ; 39° 03.1′N, 134° 20.8′E) from ooze sediments from the Yamato Bank (depth 335 m). This species is rare there and fairly varies in the strength of costation, but the characteristic features such as deeply incised sutures and pustulose intercostal trough are constant.

Remarks : This species closely resembles the end-member group of *E. juncea* (Cushman and Todd) which develops pustulose ornamentation between costae, but is separable from the latter in its fewer, sharply edged costae and smaller test size. *Euuvigerina kiyoshiasanoi* may represent a marginal morphotype, having more weakly developed costae than those of the typical form and possessing sharply edged costae, especially in its earlier portion. Todd (1948) proposed *Uvigerina cushmani* which was differentiated from *U. juncea* (= *E. juncea*) in its larger test and more strongly developed ornamentation. Her description shows, however, that the test size of *U. cushmani* is almost identical with that of *E. juncea* from the Pliocene of Timms Point, California, and her figured specimens are not so strongly ornamented. Basing upon these facts, *U. cushmani* is considered to be synonymous with *E. juncea* and different from *E. kiyoshiasanoi*. Keller's figured specimens from the Japan Trench (DSDP, Leg 57) are very small, being from 0.28 to 0.48 mm in length. Though she identified them as *U. juncea* (*E. juncea*), sharply edged costation, small test size and fusiform shape reflect that these specimens are closer to a marginal morphotye of *E. kiyoshiasanoi* than *E. juncea*. *Euuvigerina kiyoshiasanoi* is easily differentiated from *E. akitaensis* (Asano) in its pustulose ornamentation between costae.

Distribution : This species is common to rare in a depth range from 150 to 350 m in the Japan Sea. This species sometimes coexists with *E. akitaensis* in the lower part of its depth range. Fossil specimens are also found in the lower part of the Pleistocene Junicho Formation distributed in the Himi area, Ishikawa Prefecture.

Stratigraphic range: Pleistocene to Recent.

Etymology: This species is named for Dr. Kiyoshi Asano, Professor Emeritus of Tohoku University in honor of his achievements in the Japanese Tertiary smaller foraminifera.

Euuvigerina lobulata Jung, n. sp.

Pl. 29, figs. 1, 4, 5; Pl. 35, figs. 8, 9; Pl. 43, figs. 1–9.

Uvigerina peregrina Cushman. Ishiwada, 1950, fig. 8.

Uvigerina wakimotoensis (Asano). Chiji, 1959, p. 28–29, pl. 7, figs. 9–10.

Uvigerina akitaensis Asano. Asano, 1958, p. 33–34, pl. 6, figs. 12–13 (not figs. 9–11).

Uvigerina cf. *peregrina dirupta* Todd. Chiji, 1959, p. 26, pl. 7, fig. 4.

Description: Test elongate fusiform, medium in size, 0.4 to 0.7 mm in length; greatest breadth around middle portion, 2 to 3 times as long as broad; coiling triserial; some large individuals having stretched bi- to uniserial chambers in later portion; megalospheric specimen showing a slightly drooped maximum breadth toward earlier portion and blunt initial end; the microspherics rapidly increasing in chamber size, initial point being narrow V-shaped; chamber inflated; sutures distinct, incised; ornamentations combined with costation and spinosity; costae widely-spaced, thin, high in earlier portion, but rarely forming peaks overhanging along chamber base; costae serrated to spines in later portion; ornaments interrupted at apertural base; neck cylindrical, medium in length and terminated with a distinct phialine lip.

SEM observation: 1) Pore: circular to subcircular, up to 1 μm in maximum diameter (Pl. 43, fig. 8). 2) Toothplate: euuvigerine type (Pl. 29, figs. 1, 4, 5).

Soft X-ray examination: Megalospheric specimens composed of about 11 chambers, ranging from 50 to 70 μm in prolocular diameter and the microspherics, 13 to 16 chambers, about 20 μm in prolocular diameter (Pl. 35, figs. 8, 9).

Holotype: IGPS 99805, Pl. 43, fig. 3 (st. 87; 37°12.6′N, 137°12.4′E) from Toyama Bay (depth 345 m). This species is relatively common there and shows a wide range of variations in the proportion of spinosity to costation. Widely-spaced, thin and high costae are stable in earlier portion.

Remarks: This species resembles *E.* (*Hopkinsina*) *wakimotoensis* (Asano), but differs from the latter in its more strongly-developed, thin, higher costae and more compact triserial coiling. Though a series of morphotypes of this species includes specimens with uniserially developed last-formed chambers, this type is also separable from the *wakimotoensis* type in its stronger ornamentation and subglobose chambers in the later stage. *E. lobulata* differs from *E. akitaensis* (Asano) in its deeply serrated costae and spinose ornamentation in the later stage and more sharp, thinner costae in earlier and middle portions. Matsunaga's figured specimens (1963, Pl. 42, figs. 10a, b), named *Uvigerina asanoi*, are not included in a morpho-series of *E. lobulata*. His specimens show slightly serrated costae at the ultimate chamber, but they are within the range of variations of *E. akitaensis*. *E. lobulata* is also similar to *E. nipponica* Jung, n. sp. and *E. curticosta* (Cushman), but is easily distinguishable in its more elongate test shape than in the last two.

Distribution: *E. lobulata* is common to rare in the Japan Sea (depth range from 250 to 1,000 m), common at depths from 300 to 500 m. This species often coexists with *E. akitaensis*, but these two species show distinct size clouds, and it occupies a higher ratio of length to breadth than does the latter. It sometimes shows a sympatrical occurrence with *E. kiyoshiasanoi* Jung, n. sp. in the uppermost part of its depth range.

E. lobulata commonly occurs from the Pliocene Yabuta Formation distributed in the Himi area, Ishikawa Prefecture.
Stratigraphic range: Pliocene to Recent.
Etymology: The specific name *lobulata* is derived from the Latin adjective *lobulatus*.

Euuvigerina nanataniensis (Matsunaga), 1963

Pl. 49, figs. 7-9.

Hopkinsina nanataniensis Matsunaga, 1963, p. 113, pl. 42, figs. 6a, b.

Description: Test elongate, slightly compact, medium in size, 0.65 to 0.80 mm in length, greatest breadth at upper portion, about twice as long as broad; coiling triserial throughout test length, but biserially attatched chambers rarely developed in later stage; sutures distinct, depressed, but obscured by heavy ornamentation in earlier stage; chambers inflated and rapidly increasing in size toward apertural end; test ornamented with widely-spaced, thin, high, longitudinal costae which often combined with those of adjacent chambers. Costae well developed in middle stage and weakened at final chamber; apertural neck at strongly depressed base (Pl. 49, fig. 9), weak and broken out, then not descriptive.
SEM observation: 1) Pore: not visible by strong development of secondary calcification. 2) Toothplate: euuvigerine types.
Remarks: When Matsunaga (1963) proposed this species, he assigned it without referring to its coiling pattern to the genus *Hopkinsina* Howe and Wallace, which is ranked as a subgenus in this paper. He described the holotype from a sediment core which was correlated to the Nanatani Formation in surface sequences. However, the writer could not find specimens with distinct biserial coiling in materials from the Nanatani Formation outcropping at Kitaimogawa, Minami-kanbara, Niigata Prefecture. Only a few specimens carry biserial arrangements in the last-formed one or two chambers. It is not unusual that some euuvigerine forms besides species of *Hopkinsina* develop biserial coiling in the later stage. It seems unnecessary to include this species under the subgenus *Hopkinsina*.
Distribution: This species is rare in the Middle Miocene Nanatani Formation exposed at Kita-imogawa, Niigata Prefecture.
Stratigraphic range: Middle Miocene.

Euuvigerina nipponica Jung, n. sp.

Pl. 29, figs. 2, 3, 6, 7; Pl. 35, figs. 6, 7; Pl. 45. figs. 1-6.

Uvigerina peregrina dirupta Todd. Ishiwada, 1964, p. 40, 41, pl. 5, figs. 72-75.

Description: Test elongate fusiform, medium size, about 0.55 mm in length; greatest breadth at middle portion, about twice as long as broad; coiling triserial in earlier portion, but biserial, rarely uniserial, in later portion; triserial portion about two-thirds of test length; chambers in middle portion strongly inflated; periphery lobulate; sutures deeply incised, distinct due to chamber inflation; chamber size increasing rapidly in earlier portion but usually reducing at ultimate chamber; test ornamented with thin, sharp, low and longitudinal costae in earlier portion, developing serration with spinose final chamber; sutural lines cut costae; narrow intercostal trough ornamented with rows of minute spines and/or pustules, and sometimes overcasted and seen frosty; spinose ornaments continue to apertural neck, except for uppermost part of neck; final chamber rounded and concave toward coiling axis, terminated with a long and slender neck having a phialine lip.

SEM observation: 1) Pore: circular, having slightly inflated margin; about 0.4 μm in maximum diameter; 22 pores per 15×11 μm^2 square. 2) Toothplate: thick, predominant toothplate initiated on former apertural lip and running to apertural channel; imperforate (Pl. 29, figs. 2, 3, 6, 7).

Soft X-ray examination: Megalospheric proloculi show a wide range of variations in size from 60 to 100 μm; microspheric proloculi much less variable, being 20 μm; microspheric form very few in a given population, as compared with megalospheric ones. Adult test composed of 8 to 9 chambers in the megalospherics and about 11 chambers in the microspherics (Pl. 35, figs. 6, 7).

Holotype: IGPS 99815, Pl. 45, fig. 4 (TS-7; 33°02.5′N, 133°47.5′E) from Tosa Bay (depth approximately 918 m). This species is abundant there and shows a wide range of variations in the ratio of spinosity to costation, but spinosity or deeply serrated costation at final chamber and a long, slender neck are invariable.

Paratype: IGPS 99814, Pl. 45, fig. 3 (KT85-6, G-2; 34°10.6′N, 138°00.0′E) from Enshu-nada (depth 938 m). It is included in the named species as one of the end-member groups, which have the ultimate chamber with rather poor spinosity, but shows a successive morpho-series of the typical forms in the same samples.

Remarks: This species resembles several other spinose-costate forms, especially *E. curticosta* (Cushman) from off the west coast of America, but differs in its smaller and slender test, more weakly developed ornamentation and long neck. It also resembles *E. hispidocostata* (Cushman and Todd) from a Miocene section of Jamaica, but differs in its more inflated chambers and smaller test. Small specimens of *E. hispida* (Schwager) resemble end-member forms (Pl. 45, fig. 1) of *E. nipponica* whose initial end is deely serrated. Such end-member forms are also separable from the small sized *E. hispida* by its trace of costae.

Distribution: This species commonly occurs in the Kuroshio area (depths from 500 to 2,000 m, especially abundant at depths from 500 to 1,000 m). This species shows a successive morpho-series with depth. A relatively shallow morpho-group shows a higher ratio in costation to spinosity like the specimen of Pl. 45, fig. 3 and a deeper morpho-group shows much more remarkable spinosity than shallow ones, like Pl. 45, fig. 1. *E. nipponica* coexists with *E. aculeata* (d'Orbigny) and *E. curticosta* (Cushman and Todd) in the upper part of its depth range and occurs sympatrically with *E. hispida* (Schwager) in the lower part of its depth range.

Stratigraphic range: Recent.

Euuvigerina schencki (Asano), 1950

Pl. 35, figs. 1, 2; Pl. 43, figs. 10–15.

Uvigerina tenuistriata Reuss. Asano, 1938, p. 612, pl. 17(6), figs. 12, 13.

Uigerina schencki Asano, 1950, p. 17, figs. 74, 75; Asano, 1958, p. 37, pl. 6, figs. 17, 18; Kuwano, 1962, pl. 24, figs. 12–13.

Description: Test elongate, medium in size, 0.5 to 0.6 mm in length, rounded in lateral section; greatest breadth near middle portion, 2.7 to 3.4 times as long as broad; coiling triserial, sometimes bi- to uniserial in later stage, chamber slightly inflated, rapidly increasing its size in earlier portion; sutures distinctly incised; test ornamented with narrowly-spaced, distinct, thin, low, costae, which interrupted by sutures; some individuals forming two costal wings at sloping shoulders of ultimate chamber. These highly costate wings overhanging suture between ultimate and penultimate chamber so that ultimate chamber appears subtriangular;

costae not continue to apertural neck; neck cylindrical, relatively short and terminated with a distinct phialine lip.
SEM observation: 1) Pore: circular to subcircular, about 0.92 μm in diameter. 2) Toothplate: euuvigerine type.
Soft X-ray examination: Megalospheric specimens composed of about 12 chambers, clustered at 40 μm in prolocular diameter (Pl. 35, figs. 1, 2). The microspherics not found.
Remarks: This species is easily identified by its low and narrowly-spaced costation and sutural line drawing a subtriangular shape in middle portion.
Distribution: This species is rare in Recent sediments off Shimonoseki and from Enshu-nada (depths from 80 to 250 m), in warm water provinces, the Tsushima Current and the Kuroshio, respectively. Asano (1950) described the holotype from the Pliocene(?) Tomioka Formation distributed at Kamakura, Kanagawa Prefecture.
Stratigraphic range: Pliocene(?) to Recent.

Euuvigerina schwageri (Brady), 1884

Pl. 49, figs. 1-6.

Uvigerina schwageri Brady, 1884, p. 575, pl. 74, figs. 8-10; Asano, 1938, p. 612, pl. 17(6), figs. 24, 30; Asano, 1950, p. 17, figs. 76-77.
Uvigerina crassicostata Schwager. LeRoy, 1964, p. 34, pl. 4, fig. 1.

Description: Test elongate to oval, stout, large in size, 0.7 to 1.8 mm in length, greatest breadth at middle portion, 1.4 to 2.6 times as long as broad; coiling triserial; sutures depressed; chambers inflated, sometimes chamber inflations obscured by thick ornamentation; test ornamented with thick, widely-spaced, prominent costae, about 4 costae per chamber; costae most prominent in middle portion, fading down toward apertural end, and ending in marginal parts of chambers or continuing across sutures to fuse with those of adjacent chambers; apertural neck set into a distinct depression, broken out and not descriptive more.
SEM observation: 1) Pore: slit-like, 0.75 μm in mean length of major axis and 0.25 μm in that of minor axis (Pl. 49, fig. 5) 2) Toothpalte: euuvigerine type.
Remarks: The Japanese specimens is more or less different from the typical form in having a stronger depression at the apertural base. Nevertheless they hold the characteristics of *E. schwageri* such as few costations, large test size and elongate to oval test shape. This species shows a distinct dimorphism between the megalospherics (A) and microspherics (B), represented by the ratio of length to breadth and the shape of initial ends. "A" forms are much greater than "B" forms in L/B ratio and are more slender as compared with these having a broad end.
Distribution: This species is very rare in the lower part of the Pliocene Yonabaru Formation in Okinawa and in the middle part of the Pliocene Yonahama Formation in Miyako-jima. Recent specimens were obtained from Enshu-nada and Tosa Bay, at depths of 196 m and approximately 918 m, respectively, though very rare.
Stratigraphic range: Pliocene to Recent.

Euuvigerina shiwoensis (Asano), 1958

Pl. 31, figs. 1-3; Pl. 35, figs. 13, 14; Pl. 44, figs. 1-5.

Uvigerina peregrina shiwoensis Asano, 1958, p. 35, pl. 6, figs. 5-8.
Uvigerina shiwoensis Asano. Aoki, 1965, p. 56-57, figs. 3-5
Uvigerina peregrina dirupta Todd. Asano, 1950, p. 16, figs. 71-72; Kikuchi, 1964, pl. 1, fig. 30.

Description: Test broadly fusiform, medium in size, about 0.40 to 0.85 mm in

length, more or less compact, greatest breadth at middle portion, 1.5 to 2 times as long as broad; coiling triserial, sometimes ultimate chamber added biserially; sutures distinct, depressed; chambers inflated, gradually increasing its size, but biserially attatched ultimate chamber generally reducing its size; test ornamented with widely-spaced, thick, relatively high costae in earlier portion; but with serrated ones in later portion; costae discontinuous from those of adjacent chambers, but forming marginal projections of chambers, especially in earlier portion; a predominant, acicular spine at initial end in some individuals; ornaments in later portion never continue to apertural neck; neck short and terminated with a phialine lip.

SEM observation: 1) Pore: circular to slit-like, usually, subcircular on final chamber, circular pores up to 0.85 μm in diameter and having slightly inflated marginal area (Pl. 44, fig. 5). 2) Toothplate: euuvigerine type, thick and broad, generally initiated on lips of preceding apertures, sometimes placing base of toothplate across preceding aperture (Pl. 31, figs. 1-3).

Soft X-ray examination: The microspherics (B), 20 μm in prolocular diameter, the megalospherics (A) range from 90 to 130 μm (Pl. 35, figs. 13, 14); "A" form usually composed of about 9 chambers, 2 or 3 chambers fewer than in "B" form with the same test length.

Remarks: This species resembles *E. curticosta* (Cushman), but differs from the latter in having marginal projections of chambers and thicker and fewer costae. This species is also separable from *E. aculeata* (d'Orbigny) in its less developed spinosity. Asano originally proposed this morphotype as a subspecies of *E. peregrina* (Cushman). Though much more similar to *E. aculeata*, it is still morphologically distinct and is ranked as a species.

Distribution: This species is more or less common at Enshu-nada and is rare at the type locality Kii-suido (Kii-Channel) and Tosa Bay. Its depth range is from 300 to 1,000 m, having the maximum frequency at a depth of near 500 m. This species is almost the same in depth range with *E. curticosta* and *E. aculeata* in Japan. Fossil specimens are fairly common in the Pliocene Iwasaka Formation in the Boso Peninsula.

Stratigraphic range: Pliocene to Recent.

Euuvigerina yabei (Asano), 1938

Pl. 42, figs. 6-10.

Uvigerina yabei Asano, 1938, p. 613, pl. 17(6), figs. 1, 2; Cushman and Todd, 1941, p. 77, pl. 20, figs. 12, 13; Asano, 1950, p. 18, figs. 85-87; Matsunaga, 1963, pl. 43, figs. 5a, b.

Description: Test elongate, large in size, 0.8 to 1.1 mm in length; greatest breadth around middle portion, 2.5 to 3.5 times as long as broad; coiling triserial in earlier portion, but last-formed chambers bi- to uniserial in some cases; chamber inflated, more or less rapidly increasing size in earlier portion; sutures distinct, depressed; test ornamented with broad, low costae; costae prominent in early middle portion, rounded at edges, giving wavy appearance to chamber surface, 8 to 10 per chamber, discontinuous from those of adjacent chambers, fading off toward apertural end, not costate or showing only weak traces of costae at ultimate chamber; apertural neck broken, not descriptive.

SEM observation: 1) Pore: slit-like at antepenultimate chamber, about 2.6 μm in length of major axis and 0.4 μm in that of minor axis (Pl. 42, fig. 10). 2) Toothplate: euuvigerine type.

Remarks: Among the Japanese taxonomists, much confusion is associated with attempts to classify *E. yabei* (Asano), *E. juncea* (Cushman and Todd) (synonymous with *Uvigerina cushmani*

Todd), and the morpho-complex of *E. akitaensis* (Asano) including two subspecies (subsp. *grandis* Jung and subsp. *pumila* Jung). The confusion has resulted from the overestimation of non-costated features on the final chamber. This characteristic is indeed frequently observed among fully-developed specimens of several related species. Some authors simply regard *E. yabei* as a large-size group of *E. akitaensis*. *E. yabei* is separable from *E. akitaensis* complex in having broad and low costation, while the latter has thinner, higher and more sharply edged costae. *E. yabei* is also easily distinguishable from *E. juncea* in its broader, fewer costation and larger test size.

Distribution: This species is rather rare in its type locality, the Pleistocene Wakimoto Formation at Oibanazaki, Oga Peninsula, Akita Prefecture. Large and more typical specimens are common in the Pleistocene Shibikawa Formation outcropping along the Anden coast of the peninsula (locality of Asano (1950)'s hypotype). *E. yabei* is associated with *Islandiella sublimbata* (Asano and Nakamura), *Elphidium advena* (Cushman), *Porosorotalia makiyamai* (Chiji) and *Cibicides refulgens* Montfort in samples from the Shibikawa Formation.

Stratigraphic range: Pliocene to Pleistocene.

Euuvigerina sp. A

Pl. 36, figs. 11, 12; Pl. 48, figs. 1-5.

Description: Test elongate fusiform, medium in size, 0.4 to 0.6 mm in length; greatest breadth at middle portion, from 1.4 to 1.7 times as long as broad; coiling triserial; sutures distinct, depressed; test ornamented with widely-spaced, thin, distinct costae, about 7 costae per chamber, not continuing across sutures; apertural neck short, but broken down in most individuals, sometimes surrounded by projections, neck terminated with a phialine lip.

SEM observation: 1) Pore: circular, about 0.6 μm in diameter (Pl. 48, fig. 4). 2) Toothplate: euuvigerine type.

Soft X-ray examination: The microspherics composed of about 10 chambers, 20 μm in prolocular diameter; the megalospherics, about 8 chambers, 60 to 80 μm in prolocular diameter (Pl. 36, figs. 11, 12).

Remarks: This morphotype resembles *E. nitidula* (Schwager) in its widely-spaced costae, but differs in its smaller test size, relatively higher costation and short apertural neck. Though this is distinguished from *E. introrsa* Jung, n. sp. in its widely-spaced, fewer costations, it is highly possible that this morphotype represents a marginal morpho-group of the latter. Nevertheless this type does not occur with the typical *E. introrsa*. Apertural necks of the present morphotype are mostly broken down, suggesting that this type may have weaker necks than those of the typical *E. introrsa*. Similar features have been referred by several authors in the descriptions of *E. nitidula*. In these circumstances, this morphotype is left unnamed and merely referred to as *Euuvigerina* sp. A.

Distribution: This morphotype is common in the Pliocene Kawabaru Member of the Saito Formation distributed in Miyazaki.

Stratigraphic range: Pliocene.

Subgenus *Hopkinsina* Howe and Wallace, 1932
Euuvigerina (*Hopkinsina*) *imogawaensis* (Matsunaga), 1963

Pl. 49, figs. 10-12.

Hopkinsina imogawaensis Matsunaga, 1963, p. 112, pl. 42, figs. 3a, b.

Description: Test elongate fusiform, large in size, 0.8 to 1.1 mm in length; greatest breadth at middle portion in the

megalospherics, at upper third of test length in the microspherics, both about twice as long as broad; coiling triserial in earlier portion and biserial to uniserial in middle and later portions; bi- to uniserial chambers usually forming more than two-thirds of test length; microspheric specimens tapering toward initial end, rapidly increasing in chamber size; the megalospherics having a blunt, rounded initial end, more slowly increasing chamber size than the microspherics; chambers strongly inflated; sutures distinct, deeply incised; test ornamented with coarse, sharp spines; spines 1.5 times as high as broad, with cut tops (Pl. 49, fig. 12); spinose ornaments more or less continuing to apertural neck; neck cylindrical.

SEM observation: 1) Pore: covered by secondary calcified layer and not open. 2) Toothplate: euuvigerine type. 3) others: prolocular diameter of megalospherics, larger than 130 μm.

Remarks: This species resembles *E. hispida* Schwager in its spinose ornaments and large test size, but is distinguishable by its more rapidly-developed, consistently biserial coiling, as compared with lately developed, spurious (stretched) biserial coiling of *E. hispida*. *E. imogawaensis* also resembles *E.* (*H.*) *notohispida* (Finlay) from a Late Miocene sequence of New Zealand, but differs from the latter in its more sharp and more densely distributed spines.

Distribution: *E.* (*H.*) *imogawaensis* (Matsunaga) is common to rare in the lower part of the Nanatani Formation, Minamikanbara, Niigata (II).

Stratigraphic range: Early Miocene.

Euuvigerina (*Hopkinsina*) *shinboi* (Matsunaga), 1963

Pl. 31, fig. 6; Pl. 34, figs. 13, 14; Pl. 39, figs. 6-13

Hopkinsina shinboi Matsunaga, 1963, p. 113, pl. 42, figs 7a, b.

Description: Test elongate fusiform, relatively small in size, 0.30 to 0.55 mm in length; greatest breadth at middle portion, about 2 to 5 times as long as broad; coiling triserial in earlier portion, biserial to uniserial in later portion; bi- to uniserial portion usually forming about one half of test length; chambers strongly inflated, last-formed chambers sometimes subglobose and more or less interrupted; sutural lines distinct, deeply depressed; test ornamented with somewhat loosely distributed fine spines; spines aligned in several rows in earlier portion, occasionally dropping a hint of costae, prominent in middle portion; ornaments not continuing to apertural neck in general, except for randomly distributed two or three shorter spines; apertural neck long and slender, terminated with a slightly reverted lip.

SEM observation: 1) Pore: circular, 0.5 μm in opening diameter and about 20 pores per 15×11 μm^2 square. 2) Toothplate: euuvigerine type.

Soft X-ray examination: Megalospherics about 40 μm in prolocular diameter, slightly smaller than 20 μm in microspherics (Pl. 34, figs. 13, 14). Adult specimens composed of about 10 to 12 chambers.

Remarks: End-member morphotypes of *E.* (*H.*) *shinboi* superficially resembles *Neouvigerina proboscidea vadescens* (Cushman) in its small, spinose forms, but is separable from the latter in its widely-spaced, more prominent spines. This species has a wide range of variations in the ratio of length to breadth (2 to 5 times) and the poportion of bi- to uniserially coiled parts. Juvenile specimens have a narrower fusiform shape and lower proportion of bi- to uniserial coiling in test length. Biserial coiling with occasional uniserial chambers is constant characteristics in adult specimens. The apertural necks of Matsunaga's figured specimens are

broken and misguidedly described as being short.

Distribution: *E.* (*H.*) *shinboi* is common in Miocene sections exposed along the Japan Sea side; Nanatani Formation in Minami-kanbara, Niigata Prefecture and the Hinata and Sugata Formations in the Himi area, Ishikawa Prefecture. This species sometimes coexists with *E. nanataniensis* (Matsunaga).

Stratigraphic range: Early Middle to Early Late Miocene.

Euuvigerina (*Hopkinsina*) *wakimotoensis* (Asano), 1950

Pl. 30, figs. 3, 8; Pl. 33, fig. 10; Pl. 42, figs. 1-5.

Hopkinsina wakimotoensis Asano, 1950, p. 19, figs. 88-90.

Uvigerina pygmea d'Orbigny. Asano, 1938, p. 77, pl. 17(6), figs. 5-7.

Description: Test elongate fusiform, medium in size, 0.45 to 0.75 mm in length; greatest breadth at or above middle portion, 2.5 to 3.5 times as long as broad; coiling triserial in earlier portion, biserial in middle, and last one or two chambers uniserial; bi- to uniserial portion forming about two-thirds of test length in general; chambers tightly added and rapidly increasing size in earlier portion, but loosely and gradually in bi- to uniserial part; chambers strongly inflated; sutures deeply incised; periphery lobulate; test ornamented with widely-spaced, thin, sharp costae in earlier portion, costae serrated in middle, and spines developed in later portion; intercostal spines developed in some individuals; spinose ornaments not continuing to apertural neck; neck cylindrical, medium in length, terminated with a phialine lip.

SEM observation: 1) Pore: circular, about 0.4 μm in surface opening diameter, 26 pores per $15\times11\ \mu m^2$ square. 2) Toothplate: euuvigerine type.

Remarks: *E.* (*H.*) *wakimotoensis* resembles *E. lobulata* Jung, n. sp., but is differentiated by its more loose coiling, bi- to uniserial chambers in middle to later portions. End-member groups with less-developed biserial chambers are also separable from *E. lobulata* in its weaker ornamentations. *E.* (*H.*) *wakimotoensis* may have been diverged from the Pliocene *E. lobulata* during the Pleistocene. This species is also similar to *E. curticosta* (Cushman), but is easily distinguishable in its more elongate test, weakly developed ornaments and consistent bi- to uniserial coiling.

Distribution: This species was originally described from the Pleistocene Wakimoto Formation at Oibanazaki on the southern coast of the Oga Peninsula, Akita Prefecture. In the present study, it was found that this species is very rare at the type locality, but common in the same formation at Anden on the northern coast of the peninsula.

Stratigraphic range: Pleistocene.

Genus *Neouvigerina* Thalmann, 1952

Neouvigerina auberiana (d'Orbigny) *ampullacea* (Brady), 1884

Pl. 32, figs. 2, 8, 9; Pl. 34, figs. 1a, b, 2a, b, 3; Pl. 38, figs. 10-14.

Uvigerina asperula Czjzek var. *ampullacea* Brady, 1884, p. 579, pl. 75, figs. 10, 11.

Uvigerina ampullacea Brady. Cushman, 1913, p. 102, pl. 42, figs. 3a, b; Cushman, 1923, p. 162, pl. 42, figs. 5, 6.

Uvigerina auberiana d'Orbigny. Phleger, Parker and Peirson, 1953, p. 37, 38, pl. 7, fig. 31 (not figs. 30, 32, 33).

Uvigerina auberiana d'Orbigny var. *attenuata* Cushman and Renz, 1941, p. 21, pl. 3, fig. 17; Cushman and Todd, 1941, p. 44, pl. 13, figs. 6-9.

Description: Test elongate, small to medium in size, 0.3 to 0.7 mm in length, greatest breadth at lower third of test length, about 1.5 to 2.8 times as long as

broad ; test carrying a compact chamber cluster in earlier portion forming a broad initial end ; coiling compact, triserial at earlier portion, added one or two uniserial chambers in later portion ; chamber inflated ; suture slightly depressed at chamber cluster and deeply depressed in attached later chambers ; test ornamented with fine spines throughout, ornaments continuing to apertural neck ; last-formed chamber slightly drawn into neck, deeply concave along coiling axis ; neck long, cylindrical and terminated with a phialine lip (Pl. 32, figs. 2, 8, 9).

SEM observation : 1) Pore : circular, enlarged to 1.6 μm in opening diameter during fossilization (Pl. 38, figs. 12, 13). 2) Toothplate : attached to the side of preceding apertural lip with points or line (Pl. 32, figs. 2, 8, 9).

Soft X-ray examination : All treated specimens have megalospheric proloculi ranging 50 to 70 μm (Pl. 34, figs. 1a, b, 2a, b, 3).

Remarks : A morphotype of *N. auberiana ampullacea* (Brady) has been named as several different species or varieties among taxonomists. Adult specimens from Japan are identical with Cushman's specimens named *Uvigerina ampullacea* (Brady) from the Pacific and Atlantic Oceans (1913, 1923). Juvenile specimens are very similar to specimens figured by Cushman and Todd from an American Miocene section, which are the paratypes of *U. auberiana* d'Orbigny var. *attenuata* Cushman and Renz. Cushman and his co-workers took notice of such characters as compact chambers in earlier portion and attenuated ones in later portion. However, these characters are very similar to the description by Brady who presented the variety name *ampullacea* coming under *U. asperula* Czjzek. A morphotype of the variety *attenuata* is slightly different from that of the variety *ampullacea* in test size and patterns of the last-formed chamber. These differences may be more a matter of the ontogenetic series. Both types of *ampullacea* and *attenuata* occur together in the same samples from Japan. These two morphotypes show a successive distribution in both test form and size. Uchio (1960) mentioned that variety *ampullacea* Brady is within the range of variations of *U. auberiana* d'Orbigny. However, the writer separates the former morphotype as a subspecies belonging to the latter, because a compact chamber cluster in earlier portion is distinct and consistent in Japanese specimens.

Distribution : *N. auberiana ampullacea* (Brady) is common in the Late Miocene Uebaru Formation and the Pliocene Yonabaru Formation in Okinawa, and rare in the Pliocene Yonahama Formation in Miyako-jima.

Stratigraphic range : Late Miocene to Pliocene.

Neouvigerina interrupta (Brady), 1879

Pl. 34, figs. 11, 12 ; Pl. 39, figs. 1-5.

Uvigerina interrupta Brady, 1879, p. 60, pl. 8, figs. 17-18 ; Brady, 1884, p. 580, pl. 75, figs. 12-14 ; Cushman, 1913, p. 103-104, pl. 44, figs. 1a-c.

Uvigerina sp. Asano, 1958, p. 38, pl. 7, fig. 3.

Neouvigerina interrupta (Brady). Barker, 1960, p. 156, pl. 75, figs. 12-14.

Description : Test elongate, small to medium in size, 0.3 to 0.6 mm in length, maximum breadth at penultimate chamber, about 3.6 to 4.5 times as long as broad ; coiling triserial at initial end, up to biserial in middle portion, uniserial in late portion ; chambers strongly inflated, subglobose, compactly aggregated in initial end and loosely setting in later portion, and deeply concave inward coiling axis ; last-formed chambers interrupted, only connected with preceding ones by apertural necks in adult specimens ; sutures deeply incised ; test ornamented with densely

distributed spines, ornaments continuing to apertural neck, except uppermost part of neck; neck long, cylindrical, having a depressed line along longitudinal axis, and terminated with a phialine lip.
SEM observation: 1) Pore: minute, circular; 2) Toothplate: neouvigerine type.
Soft X-ray examination: Microspheric specimens having about 11 chambers, 20 μm in prolocular diameter; megalospherics about 9 chambers, 30 μm (Pl. 34, figs. 11, 12).
Remarks: *N. interrupta* is easily differentiated from other uvigerinid groups in its subglobose chambers and interrupted coiling in later portion.
Distribution: This species has a wide range of depth distribution (150 to 1,000 m). It is rarely found in the Kuroshio area off southwestern Japan. Among several samples, sediments (TS-6) from Tosa Bay (approximate depth 825 m) include relatively large specimens of common occurrence. It often coexists with *N. proboscidea vadescens* (Cushman).
Stratigraphic range: Recent.

Neouvigerina proboscidea (Schwager), 1866

Pl. 32, figs. 4, 5, 7; Pl. 34, figs. 9, 10; Pl. 38, figs. 1-7.

Uvigerina proboscidea Schwager, 1866, p. 250, pl. 7, fig. 96; Cushman, 1939, p. 151, pl. 10(6), fig. 13; Cushman and Todd, 1941, p. 73-74, pl. 17, fig. 9, pl. 19, figs. 3-9; Asano, 1953, p. 4, pl. 2, figs. 29-31; Drooger, 1953, p. 136, pl. 21, fig. 28; Asano, 1958, p. 35-36, pl. 6, figs. 14-16; LeRoy, 1964, p. 35, pl. 16, fig. 8; Borsetti *et al.*, 1986, p. 218, pl. 12, figs. 1-4.
Neouvigerina proboscidea (Schwager). Srinivasan and Sharma, 1980, p. 52, 53, pl. 7, fig. 21.

Description: Test fusiform, medium in size, 0.4 to 0.7 mm in length; greatest breadth at middle portion, about twice as long as broad; coiling triserial in early portion, up to biserial in later portion; chambers inflated to form lobulate periphery, rapidly increasing their size in earlier portion to maximum size in middle portion. Microspheric individuals much strongly tapered toward initial end, more inflated in middle portion, and larger than megalospheric ones; sutures distinct, slightly depressed; test ornamented with fine spines throughout test length and having a predominant acicular spine at initial end, spinose ornament continuing to apertural neck, except uppermost part of neck terminated with a distinct phialine lip.
SEM observation: 1) Pore: circular, about 0.3 μm in diameter, minute calcitic grains compactly distributed in pore margin (Pl. 38, fig. 7). 2) Toothplate: formed by folding of apertural and chamber wall inward apertural channel, attached to upper part of preceding neck side and curved to form "U" shaped trough in apertural channel (Pl. 32, figs. 4, 5, 7).
Soft X-ray examination: Megalospherics about 50 μm in prolocular diameter; microspherics about 20 μm (Pl. 34, figs. 9, 10). Adult tests composed of about 8 chambers in megalospherics and about 11 in microspherics.
Remarks: *N. proboscidea* from Japan is very similar to the specimens figured by Cushman from the type locality of this species (a Pliocene sequence at Car Nicobar Island). *N. proboscidea* (*s.s.*) is easily separable from *N. proboscidea vadescens* (Cushman) in its larger test size, lower ratio of the length of apertural neck to test length and less chamber inflation than in the latter. This species also resembles *N. setosa* Jung, n. sp. but the latter is smaller and has prominent, strong spines.
Distribution: This species is rare in Recent sediments from the Kuroshio area off southwestern Japan. It ranges in water depth from 500 to 1,000 m. It coexists with several spino-costate

species at the sample locality (Enshu-nada) such as *Euuvigerina nipponica* Jung, *E. curticosta* (Cushman) and *E. shiwoensis* (Asano). Among these coexistent species, *N. proboscidea* occupies the smallest test size cloud. It is also common to rare in the Pliocene Yonabaru Formation in Okinawa Island.
Stratigraphic range: Pliocene to Recent.

Neouvigerina proboscidea vadescens (Cushman), 1933

Pl. 34, figs. 7, 8; Pl. 37, figs. 8-11

Uvigerina proboscidea Schwager var. *vadescens* Cushman, 1933, p. 85, pl. 8, figs. 14, 15; Kuwano, 1962, pl. 24, fig. 9.

Description: Test elongate fusiform, small in size, about 0.3 mm in length; greatest breadth at middle portion, about 2.5 times as long as broad; coiling triserial in earlier portion, biserial in later portion; chambers strongly inflated to form lobulate periphery; sutures deeply incised and curved in coiling direction; chamber size increasing rapidly in earlier portion to maximum in middle portion, attenuated in late portion; test ornamented with very fine and dense spines throughout test length and a distinct acicular spine; ornaments continuing to apertural neck, except just below lip; neck cylindrical, slender, long and terminated with a phialine lip.
SEM observation: 1) Pore: circular, about 0.2 μm in diameter, about 6 pores per $15 \times 11\ \mu m^2$ square (Pl. 37, fig. 10). 2) Toothplate: neouvigerine type.
Soft X-ray examination: 18 to 30 μm in prolocular diameter; adult tests commonly composed of 8 to 10 chambers (Pl. 34, figs. 7, 8).
Remarks: This form resembles *N. takayanagii* Jung, n. sp., but is distinguishable by its totally spinose ornamentation.
Distribution: This form is common to rare in Recent sediments from the Kuroshio area off southwestern Japan. This subspecies often occurs together with *N. takayanagii*, implying their sympatry.
Stratigraphic range: Recent.

Neouvigerina pseudoampullacea (Asano), 1938

Pl. 34, figs. 4a, b; Pl. 38, figs. 8, 9.

Uvigerina pseudoampullacea Asano, 1938, p. 613, pl. 17(6), figs. 28, 29.

Description: Test strongly elongate fusiform, medium in size, about 0.65 mm in length; greatest breadth at cylindrical parts in middle portion, 3.0 to 3.5 times as long as broad and compressed to coiling axis; coiling triserial in earlier portion with initial point, biserial in late portion; chambers strongly inflated in middle portion; periphery lobulate; suture distinct and depressed, cutting horizontally chamber margin in earlier portion; test ornamented with fine spines, which sometimes aligned in rows along longitudinal axis in earlier and middle portions; ornaments continuing to apertural neck; long, cylindrical neck terminated with a phialine lip (Pl. 34, figs. 4a, b).
SEM observation: 1) Pore: minute, circular (Pl. 38, fig. 9). 2) Toothplate: neouvigerine type.
Soft X-ray examination: Megalospherics about 60 μm in prolocular diameter (Pl. 34, figs. 4a, b); microspheric specimens not detected. Adult individuals composed of about 10 chambers.
Remarks: *N. pseudoampullacea* resembles several spinose species, but is easily differentiated by its compressed test to the longitudinal axis.
Distribution: This species is very rare in the Kuroshio area off southwestern Japan. It ranges in water depth from 80

to 400 m.
Stratigraphic range: Recent.

Neouvigerina setosa Jung, n. sp.

Pl. 32, figs. 1, 3, 6; Pl. 34, figs. 5, 6; Pl. 37, figs. 1-7.

Description: Test elongate fusiform, small in size, 0.3 to 0.4 mm in length; greatest breadth at middle portion, 1.8 to 2.5 times as long as broad; coiling triserial in earlier portion, biserial with occasional uniserial chambers in late portion; chambers in middle portion strongly inflated to form lobulate periphery; sutures depressed, distinct due to chamber inflation; chambers increasing rapidly in size in earlier portion, slightly attenuated at ultimate end in usual case; test ornamented with coarse, predominant spines throughout and a distinct acicular spine at initial end; ornaments continuing to cylindrical neck; final chamber concave toward coiling axis, terminated with long, slender neck having a phialine lip (Pl. 32, figs. 3, 6; Pl. 34, figs. 5, 6).
SEM observation: 1) Pore: circular, 0.5 μm in diameter, 15 pores per 15×11 μm^2 square (Pl. 37, fig. 6). 2) Toothplate: deeply folded, attached to the side of preceding apertural neck so as to embraces upper part of neck (Pl. 32, figs. 1, 3, 6).
Soft X-ray examination: 20 to 30 μm in prolocular diameter. Though not so distinct in prolocular size, the microspheric form is distinguished from the megalospheric one in a more rapidly tapering test in earlier portion and having more inflated chambers in middle portion (Pl. 34, figs. 5, 6). Adult tests are generally composed of 8 to 10 chambers.
Holotype: IGPS 99857, Pl. 37, fig. 1 (G-77) from sea cliff 1 km northwest of Fukuyama, Hirara City, Miyako-jima, Okinawa Prefecture; upper part of Pliocene Oura Formation. This species very abundant there; numerous specimens are coarsely spinose.
Paratype: IGPS 99860, Pl. 37, fig. 4 (G-77) from the same sample that yielded the holotype specimen. This type slightly differs from the holotype in having spines arranged in several rows, but are coarsely spinose.
Remarks: *N. setosa* resembles several small species having spinose ornaments, but is easily differentiated by its coarse spine. Among related species from and around Japan, *N. proboscidea vadescens* (Cushman) resembles in general features, but differs from *N. setosa* in having shorter and much more delicate spines.
Distribution: This species is only found in samples from the upper Oura Formation assigned to a Pliocene age. It is very abundant there, excluding other uvigerinid species.
Stratigraphic range: Pliocene.
Etymology: The specific name *setosa* is derived from the Latin adjective *setosus*.

Neouvigerina takayanagii Jung, n. sp.

Pl. 37, figs. 12-17.

Description: Test elongate fusiform, relatively small, 0.30 to 0.45 mm in length; greatest breadth at middle portion, 2.0 to 2.6 times as long as broad, slightly compressed to coiling axis so that sometimes rounded triangle in lateral section; coiling triserial in earlier portion, usually biserial to uniserial in later portion; chambers inflated, fairly attenuated in late portion; suture depressed, distinct; test ornaments combined with spinosity and costation; costae well developed in middle portion, its intercostal trough studded with spines; fine and short spines developing at initial end with a predominant acicular spine, and in late portion; spinose ornament at ultimate chamber continuing to apertural neck, except upper part of neck; neck medium in

length, having a phialine lip; a single specimen possessing two complete apertures at ultimate chamber.

SEM observation: 1) Pore: circular, enlarged by any post-mortem effects (Pl. 37, fig. 16). 2) Toothplate: neouvigerine type.

Holotype: IGPS 99864, Pl. 37, fig. 14 (TS-6; 33°06.5′N, 133°47.5′E) from Tosa Bay (depth approximately 825 m). This species is rare there and shows a wide range of variations in the propotion of spinosity to costation. However, such characters as slightly compressed tests, perfectly developed spines at the final chamber and an acicular spine are quite constant.

Paratype: IGPS 99865, Pl. 37, fig. 15 (KT85-6, G-4; 34°34.2′N, 138°00.0′E) from Enshu-nada (depth 187 m). It differs from the holotype in having more strongly developed costae in middle portion and smaller in test size. This type still possesses basic characteristics such as a spinose final chamber, slightly compressed test shape and a germinal acicular spine at the initial end.

Remarks: *N. takayanagii* resembles *N. proboscidea vadescens* (Cushman) reported from Guam Anchorage, Ladrone Islands (approximately 38 m deep), but differs in its compressed test shape, costate ornament in middle portin and larger test size.

Distribution: This species is common to rare in the Kuroshio area off southwestern Japan. It ranges in water depth from 150 to 1,000 m, and shows a wide range of variations with depth; shallower specimens have well-developed costae in the middle portion of the test, as compared with deeper ones. In the lower part of its depth range, it sometimes has only a trace of costae. *N. takayanagii* commonly coexists with *N. proboscidea vadescens* whose tests are ornamented with spines throughout the test length.

Stratigraphic range: Recent.

Etymology: This species is named for my supervisor, Professor Yokichi Takayanagi of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University, in honor of his large contribution to Japanese foraminiferology.

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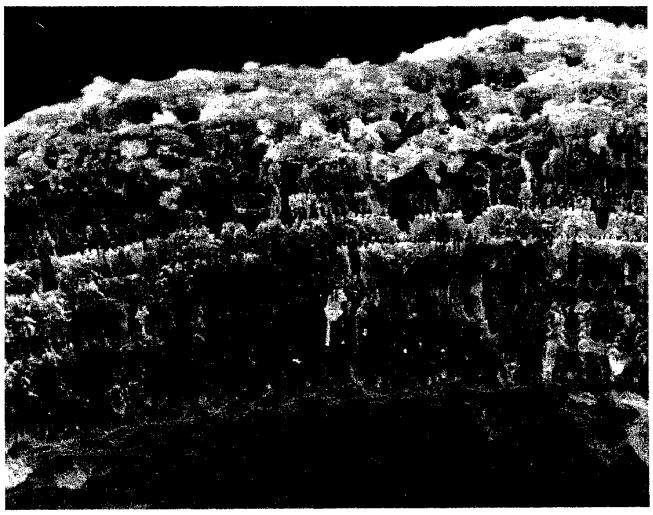
Plate 25

(All figures are scanning electron micrographs)

Figs. 1-3. *Euuvigerina akitaensis* (Asano)

Polished and etched cross sections, showing lamellar development through ontogeny.

1. Early middle portion showing subsequently deposited lamellae. Note each lamellar thickness decreasing gradually upwards and some pore tubules continued to succeeding lamellae, especially in lower part of section. ×1,600.
2. Ultimate and penultimate chamber walls, showing that ultimate chamber is simply attached to penultimate chamber, without lamellarity. PL: primary calcitic lamella; SL: secondary calcitic lamella. ×850.
3. Initial portion showing well-developed lamellarity. Note that second chamber is simply attached to proloculus, complete lamellarity which covers entire anterior chambers including proloculus is carried out from 3rd to 5th chamber episodes, and from 6th chamber onward, subsequent lamellae are pinched out toward initial. PR: proloculus; III, IV, V, VI: 3rd, 4th, 5th, and 6th chamber lamella, respectively; P: primary calcitic lamella; S: secondary calcitic lamella. ×850.



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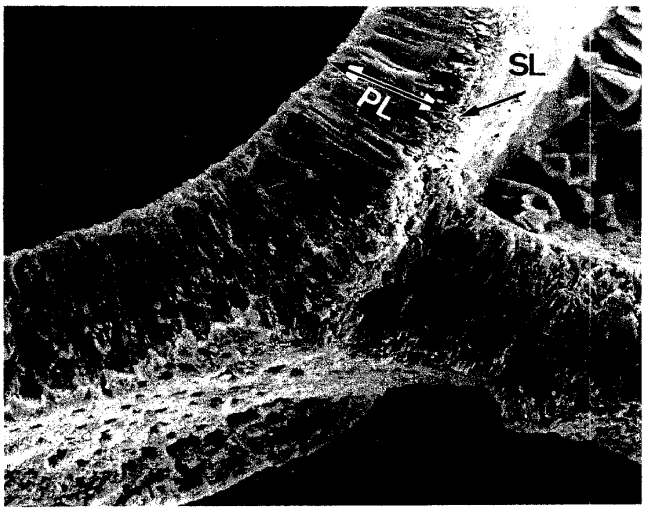

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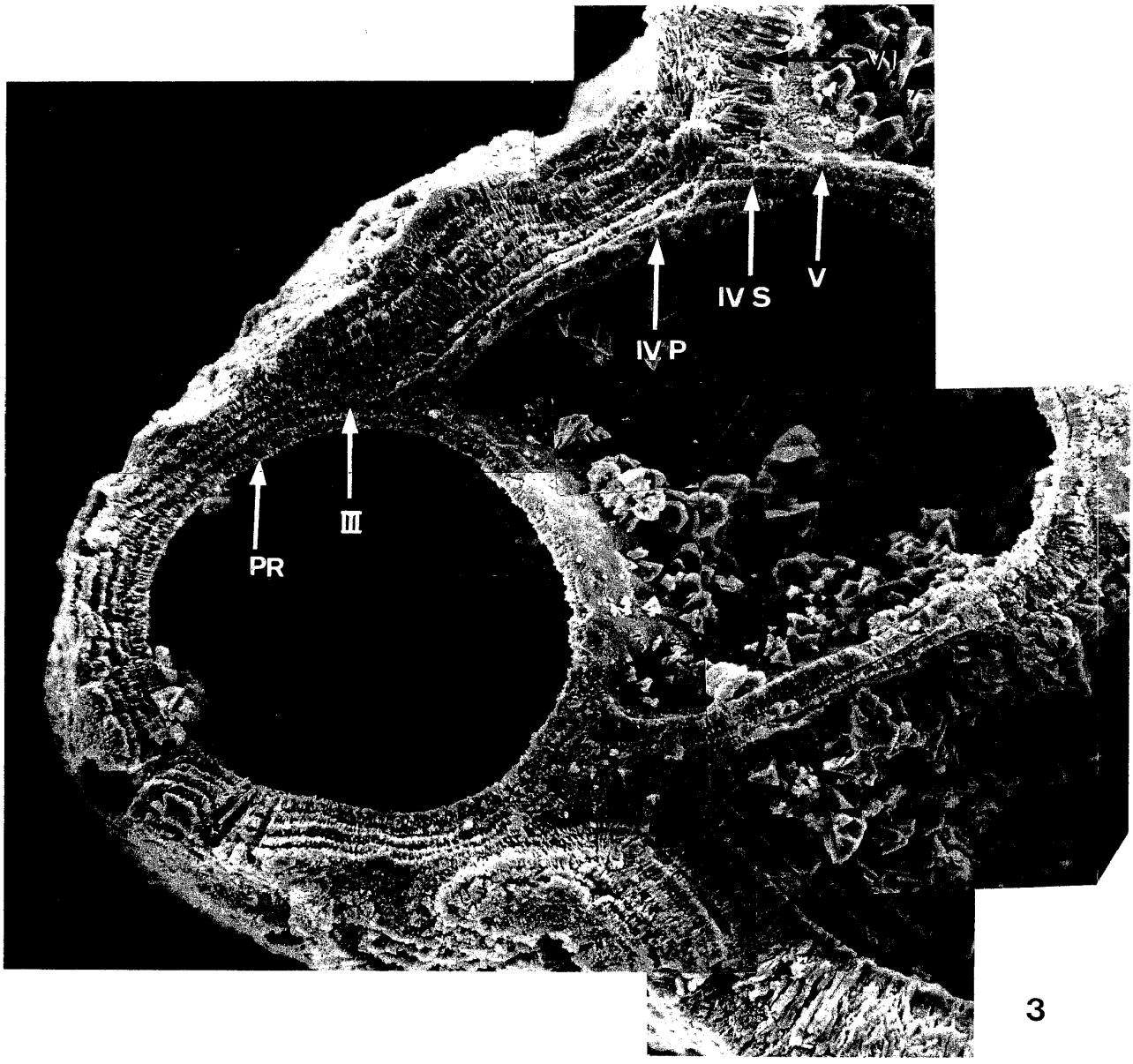

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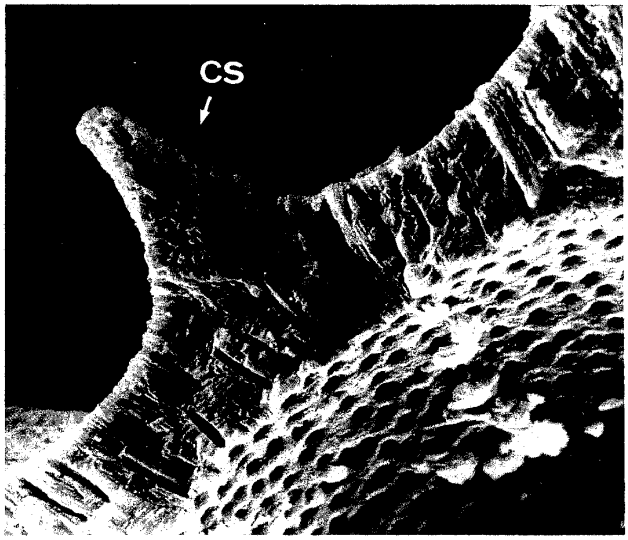

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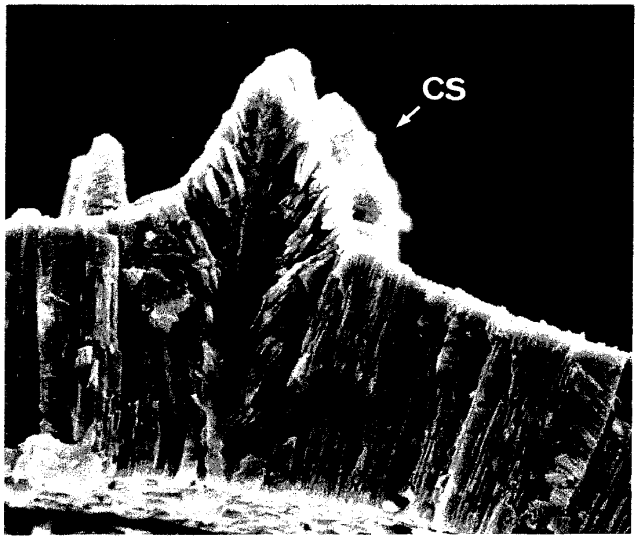

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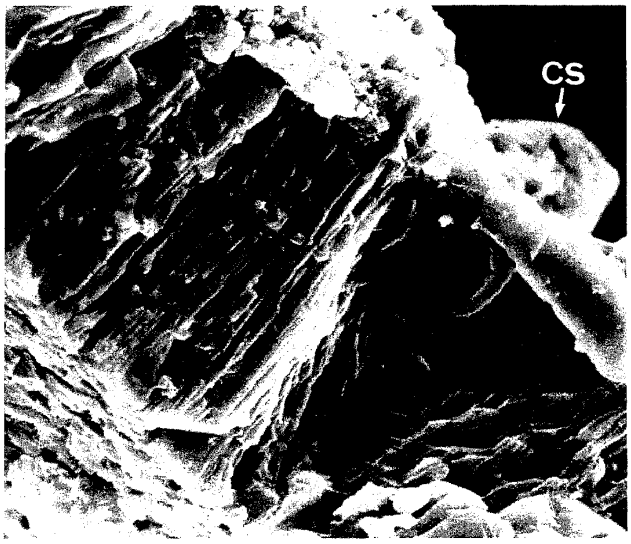

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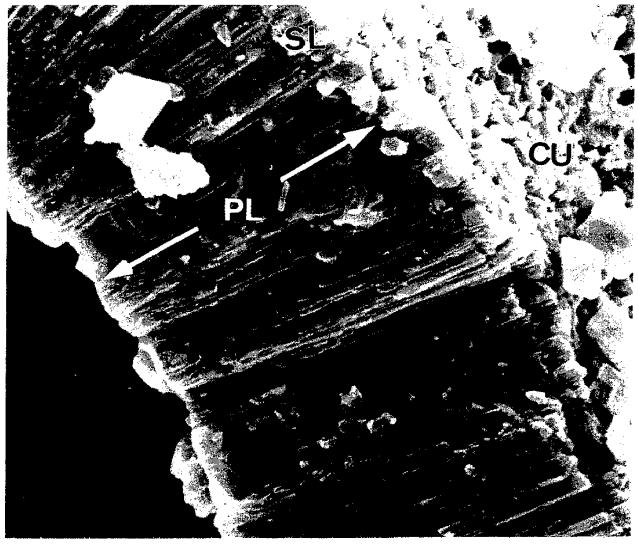

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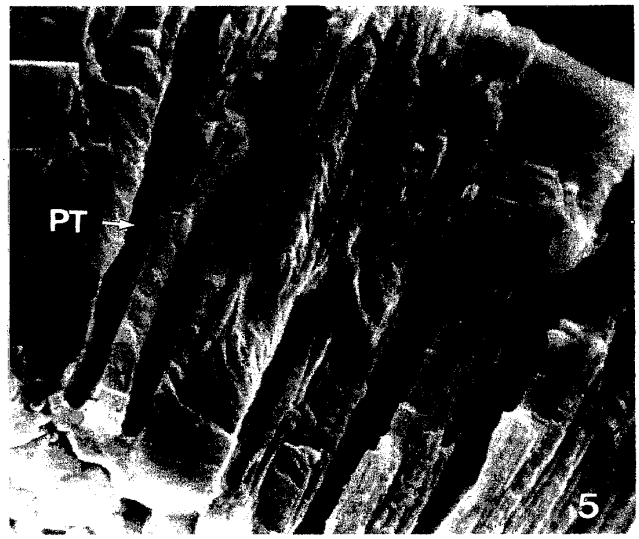

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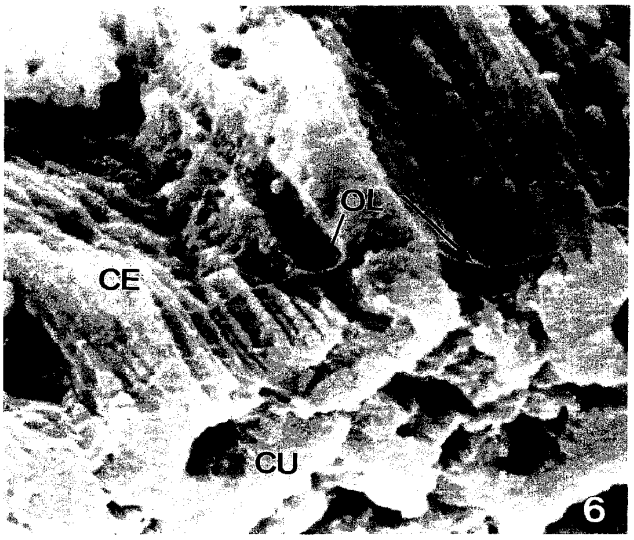


6

Plate 26

(All figures are scanning electron micrographs)

Fig. 1. *Euuvigerina* (*Hopkinsina*) *wakimotoensis* (Asano)
Etched and fractured specimen, showing wall structure of costae and inner pores.
Note that crystal elements of costate wall are oblique to those of non-costate wall.
CS : costae. ×1,600.

Figs. 2–4, 6. *Euuvigerina akitaensis* (Asano)

2. Etched and fractured specimen, showing wall structure of costae. Crystals of costate wall are branched from center of costa and take chevron form. Note piles of minute plates near pore tubules. CS : costae. ×1,600.
3. Etched and fractured specimen, showing 'V'-shaped space formed by removing costal base. CS : costae. ×2,600.
4. Etched and fractured specimen, showing fibrous wall which is divided into two parts, primary calcitic lamella (PL) and secondary calcitic lamella (SL). ×2,600.
6. Etched and fractured specimen, showing that numerous crystal elements (CE) are bundled into crystal unit (CU). Note that inner pores are placed within crystal units. OL : organic layer. ×6,000.

Fig. 5. *Euuvigerina akitaensis grandis* Jung, n. subsp. Non-etched and fractured specimen, showing pore tubules (PT) penetrating calcitic wall. Note piles of minute plates. ×3,900.

Plate 27

(All figures are scanning electron micrographs)

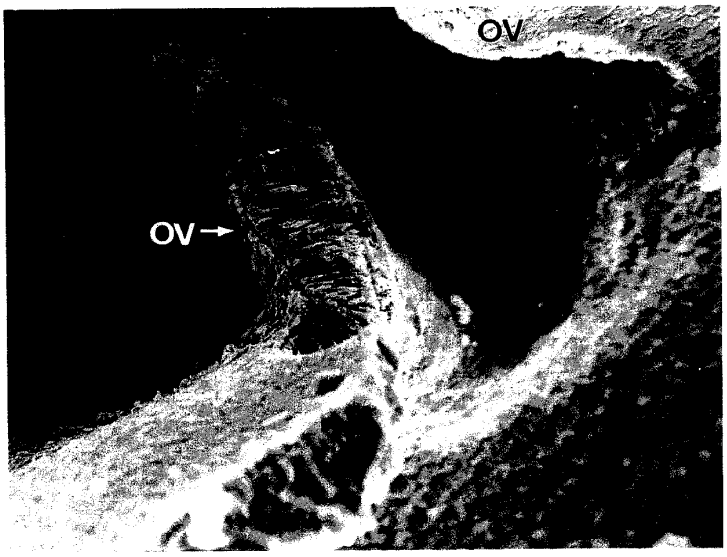
Fig. 1. *Euuvigerina akitaensis grandis* Jung, n. subsp.
Etched and fractured neck, showing that fibrous calcite wall is covered with imperforate inner and outer veneers. OV : outer veneer. ×850.

Fig. 2. *Euuvigerina akitaensis* (Asano)
Polished and etched neck, showing that perforate wall is sandwiched between two imperforate, inner and outer veneers and that wall thickness of neck is shinning toward apertural lip. TP : toothplate ; IV : inner veneer ; OV : outer veneer : LP : lip base. ×850.

Figs. 3, 5, 6. *Euuvigerina juncea* (Cushman and Todd)

3. Fractured specimen, showing inflated and imperforate andoanulus (AD) at apertural base. Note that toothplate (TP) runs straight up and turns its free part into apertural channel near andoanulus. ×850.
5. Inside view of fractured specimen, showing distinct, ring-like andoanulus (AD) and trace of toothplate (TP). Note that inner veneer is removed by natural etching. ×850
6. Inside view of fractured specimen, showing that chamber wall is folded inwards and that wall thickness is thinning toward folded part which is developed to toothplate (TP). Note apertural base imperforate. ×850.

Fig. 4. *Euuvigerina kiyoshiasanoi* Jung, n. sp.
Sectioned specimen, showing that imperforate apertural channel (AC) and toothplate (TP). ×850.



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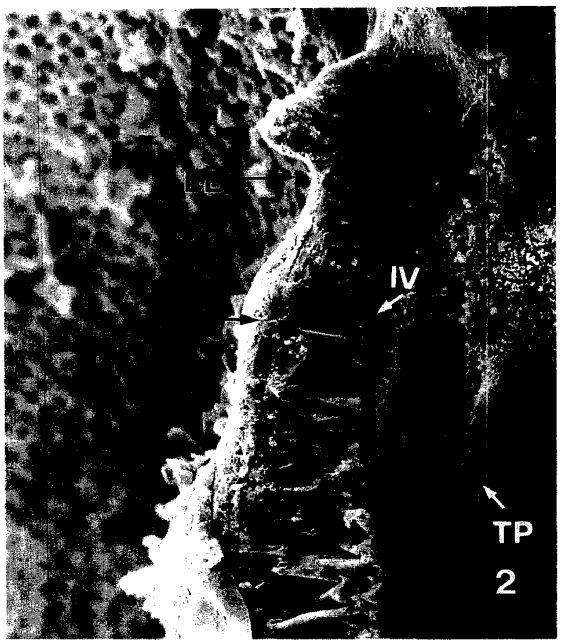

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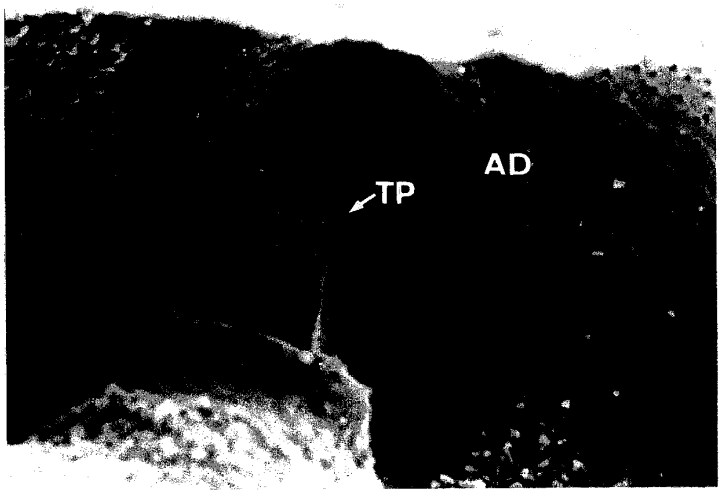

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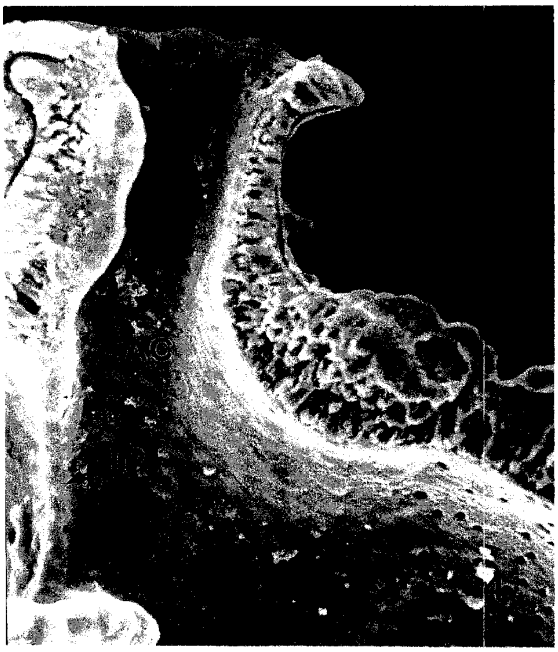

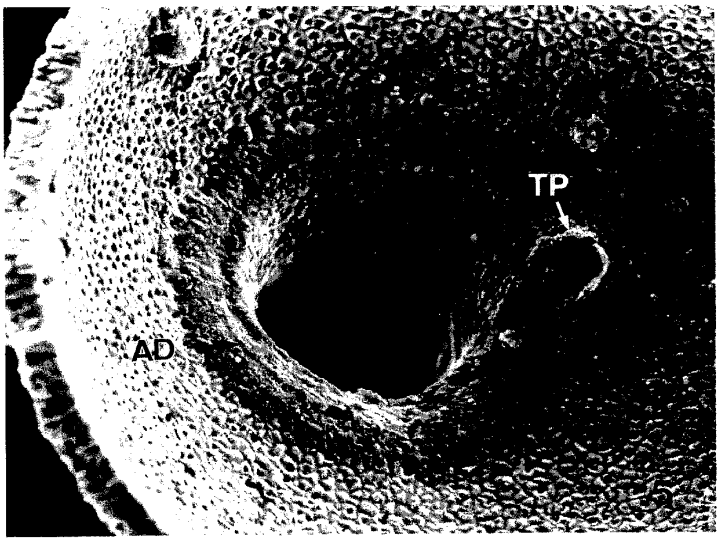

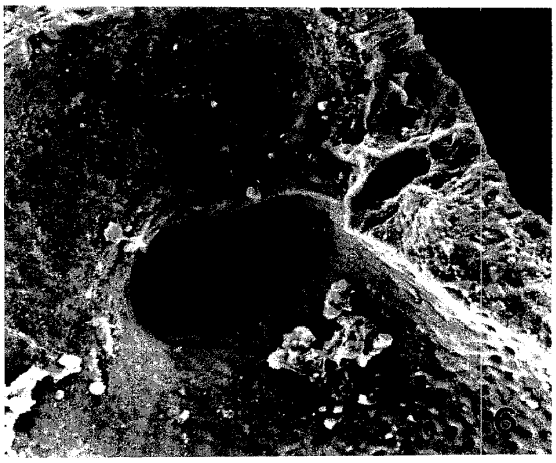

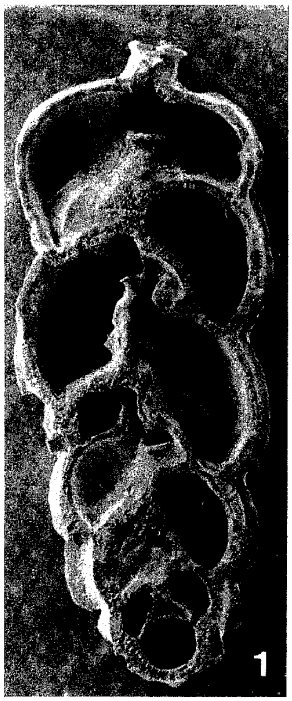
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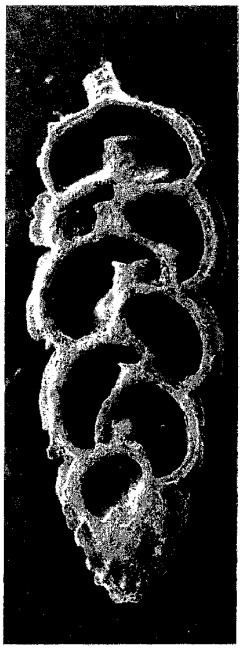
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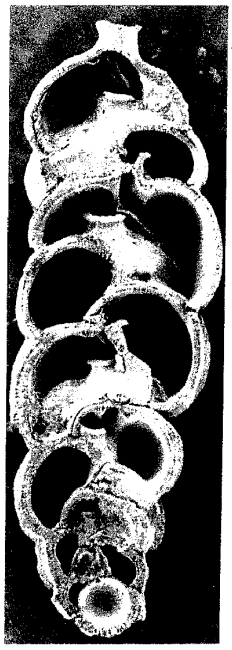
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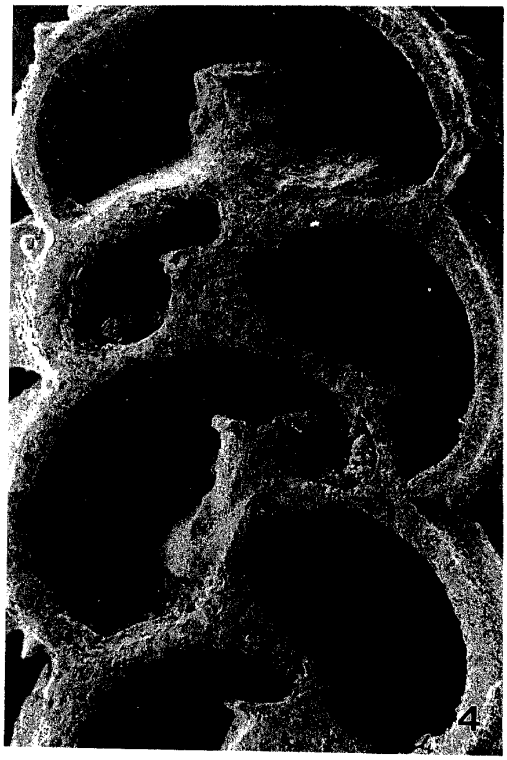
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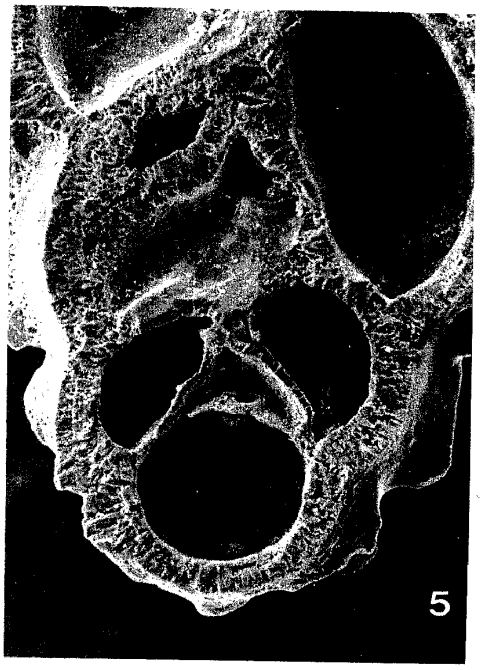
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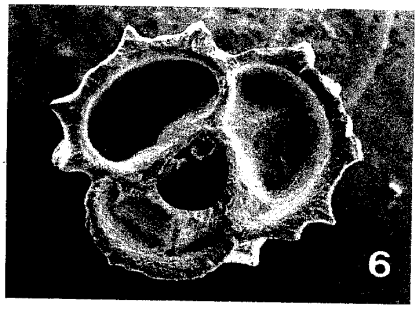
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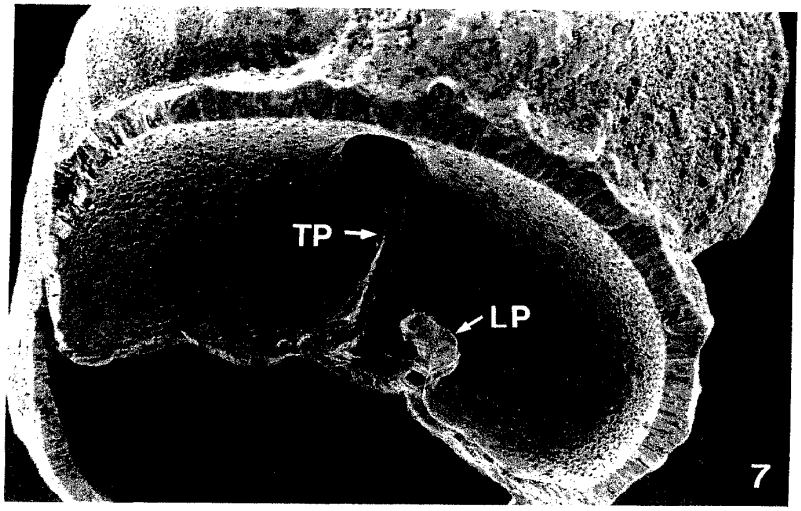
TP
LP
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AC
8

Plate 28

(All figures are scanning electron micrographs)

Figs. 1–8. *Euuvigerina akitaensis grandis* Jung, n. subsp.

1–3. Sectioned specimens, showing ontogenetic development of toothplate and internal structure. 1. ×80; 2, 3. ×57.

4. Enlargement of middle portion of Fig. 2. ×170.

5. Enlargement of earlier portion of Fig. 1, showing an aperture of proloculus. ×250.

6. Sectioned specimen, showing horizontal view. ×120.

7. Sectioned specimen, showing toothplate (TP) attached to the former apertural lip (LP). ×250.

8. Cross section of toothplate, showing that chamber wall of left side is folded inwards and forms a toothplate (TP), and wall of right side runs against the side of toothplate. AC: apertural channel. ×1,200.

Plate 29

(All figures are scanning electron micrographs)

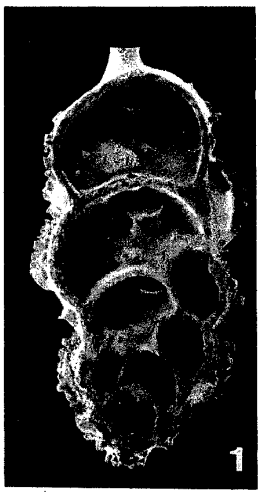
Figs. 1, 4, 5. *Euuvigerina lobulata* Jung, n. sp.

1. Sectioned specimen, showing internal structure. ×80.
4. Details of antepenultimate chamber of Fig. 1, showing imperforate andoanulus (AD) and toothplate. ×580.
5. Details of earlier portion of Fig. 1, showing that toothplate is faced to preceding one at an angle of 120 degrees. ×850.

Figs. 2, 3, 6, 7. *Euuvigerina nipponica* Jung, n. sp.

2, 3. Sectioned specimens, showing internal structure. Both, ×80.

6. Sectioned specimen, showing imperforate apertural base and toothplate. ×380.
7. Details of antepenultimate chamber of Fig. 2, showing that imperforate toothplate is placed on lip of preceding aperture and runs straight up to apertural channel with one narrow side attached to inner side of apertural neck. ×850.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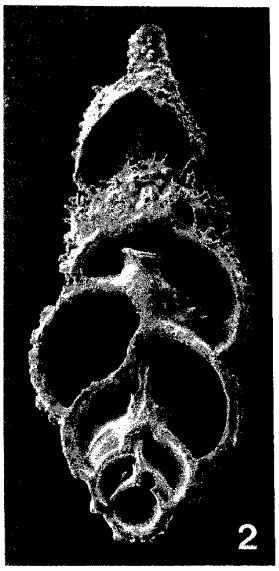
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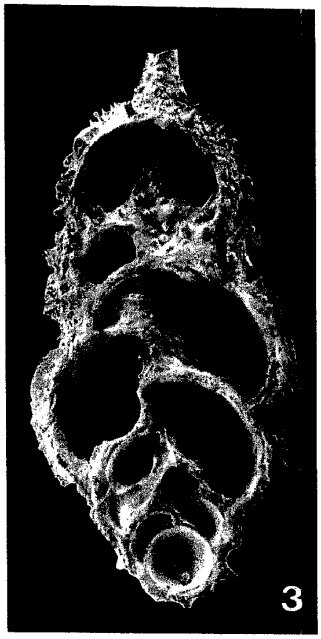
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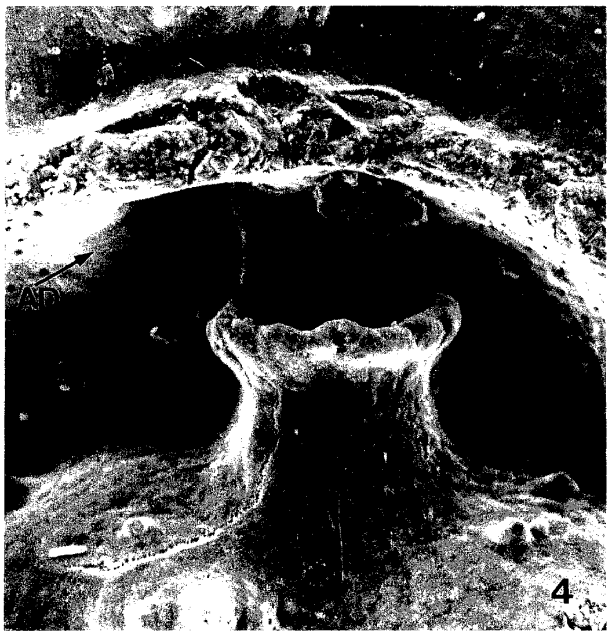
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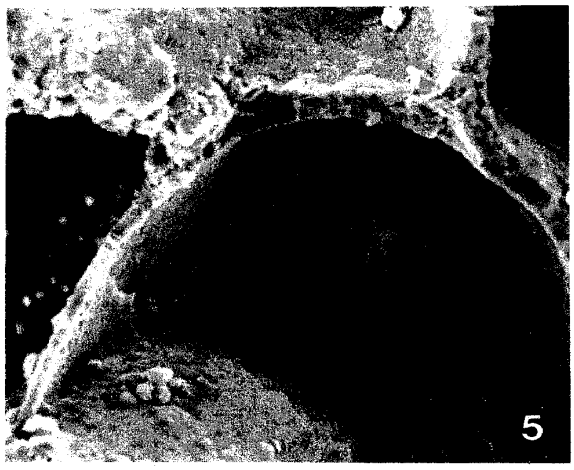
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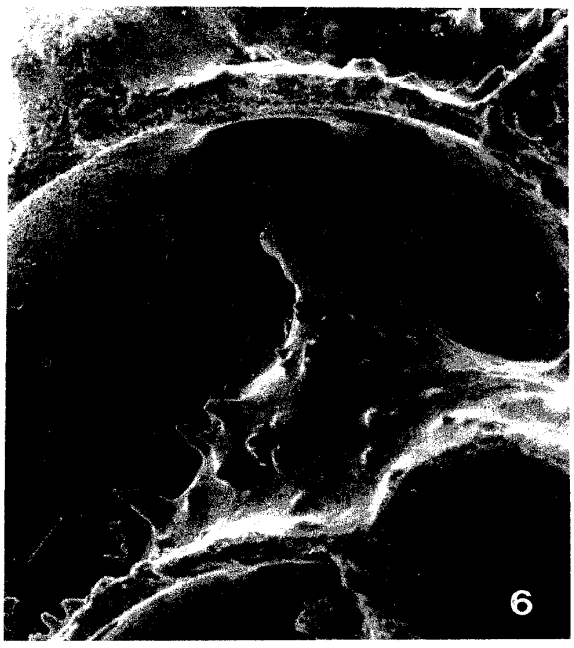
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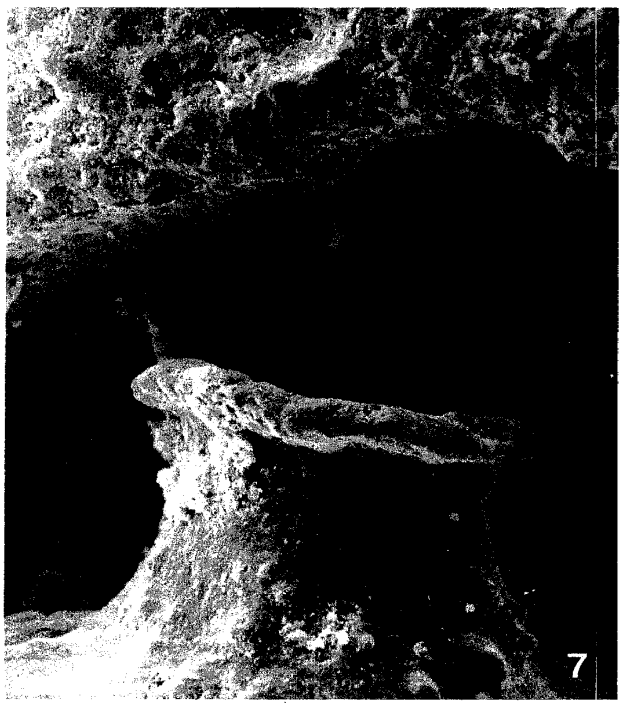
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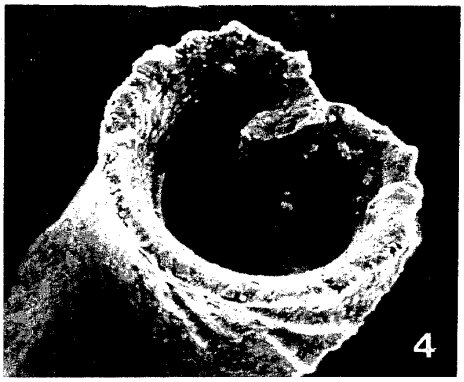
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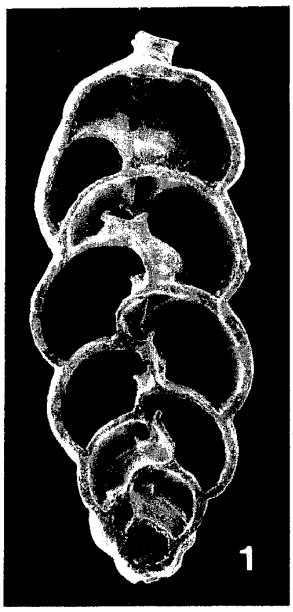
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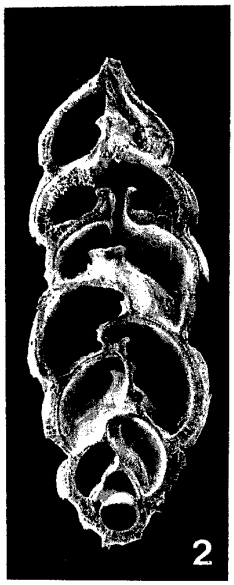
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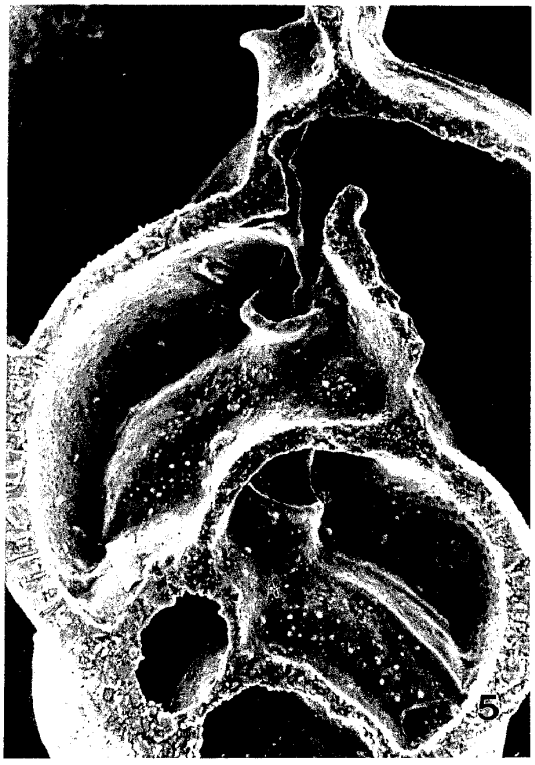
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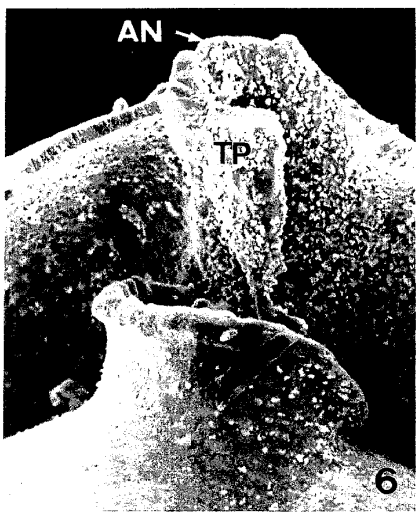
AN
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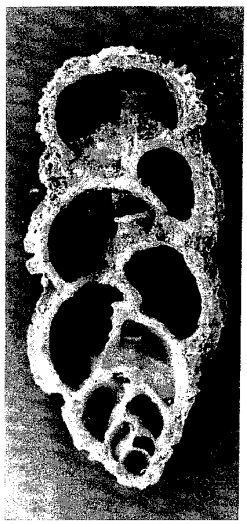

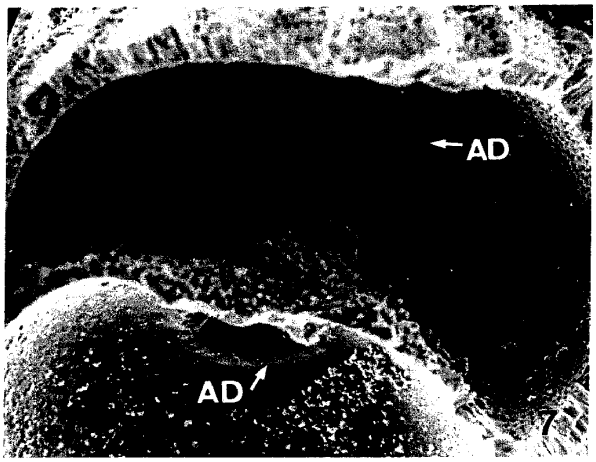
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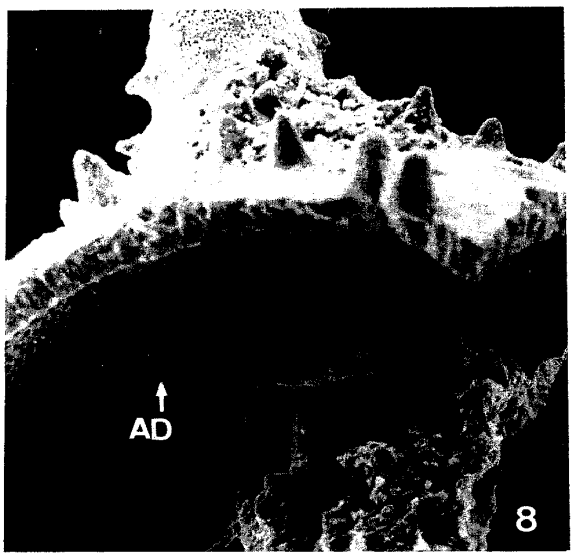

AD
8

Plate 30

(All figures are scanning electron micrographs)

Figs. 1, 4–7. *Euuvigerina juncea* (Cushman and Todd)

1. Sectioned specimen, showing internal structure. ×80.
4. Apertural view of toothplate. ×580.
5. Enlargement of Fig. 1, showing pattern of toothplates at early middle portion. ×380.
6. Fractured ultimate chamber, showing a curved toothplate. TP : toothplate ; AN : apertural neck. ×380.
7. Fractured specimen, showing a well-developed andoanulus (AD) at apertural bases. ×380.

Fig. 2. *Euuvigerina kiyoshiasanoi* Jung, n. sp.

Sectioned specimen, showing internal structure. ×80.

Figs. 3, 8. *Euuvigerina* (*Hopkinsina*) *wakimotoensis* (Asano)

3. Sectioned specimen, showing internal structure. ×80.
8. Fractured specimen, showing toothplate of ultimate chamber and apertural neck of penultimate chamber. Note that imperforate area around andoanulus (AD) is clearly distinguished from perforate area of chamber. ×580.

Plate 31

(All figures are scanning electron micrographs)

Figs. 1-3. *Euuvigerina shiwoensis* (Asano)

1. Sectioned specimen, showing internal structure. ×80.
2. Sectioned specimen, showing that abnormally developed toothplate lies across the surface of preceding aperture. ×80.
3. Details of late portion of Fig. 1, showing well-developed toothplates placed on preceding lip and distinct imperforate area, andoanulus (AD). ×380.

Fig. 4. *Euuvigerina flintii* (Cushman)

Sectioned specimen, showing internal structure. Note thick toothplates. ×120.

Fig. 5. *Euuvigerina introrsa* Jung, n. sp.

Sectioned specimen, showing internal structure. ×80.

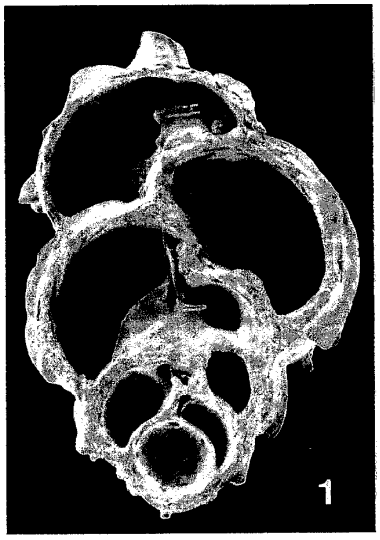
Fig. 6. *Euuvigerina* (*Hopkinsina*) *shinboi* (Matsunaga).

Sectioned specimen, showing internal structure. Note well-preserved long neck. ×120.

Figs. 7-9. *Euuvigerina hispida* (Schwager)

7, 8. Sectioned specimens, showing internal structure. Both, ×80.

9. Details of middle portion of Fig. 8, showing inflated and imperforate andoanulus (AD) and toothplate. ×580.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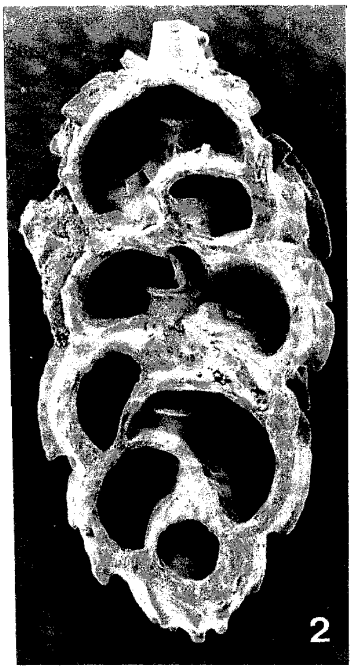
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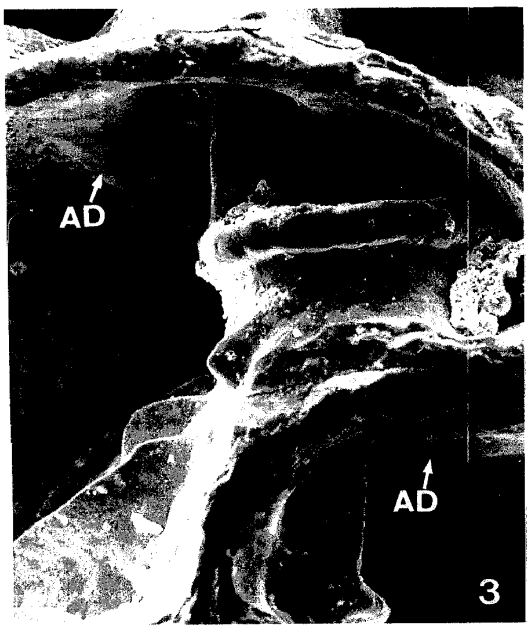
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AD
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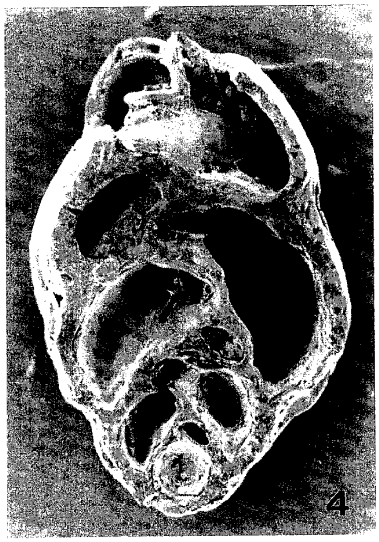
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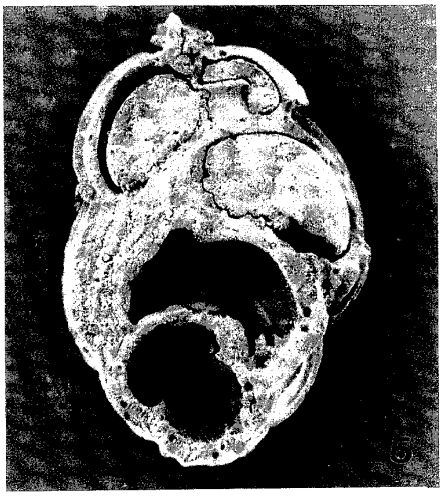

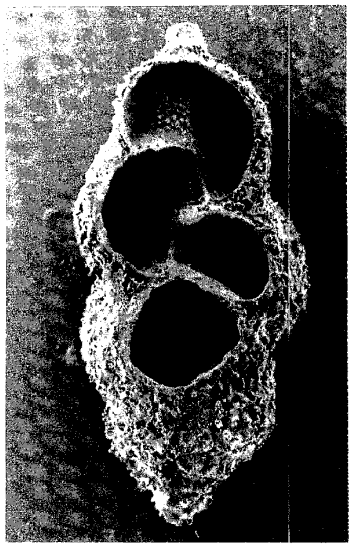

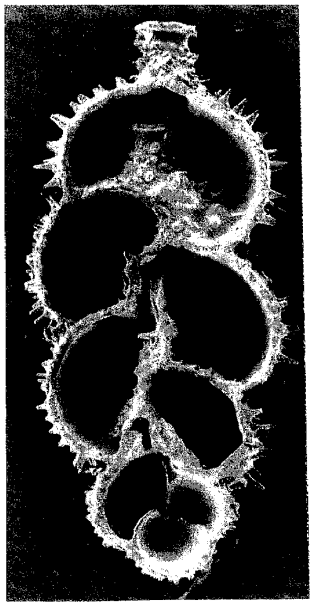

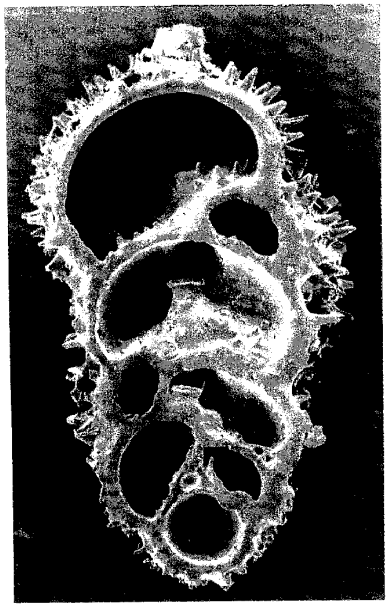

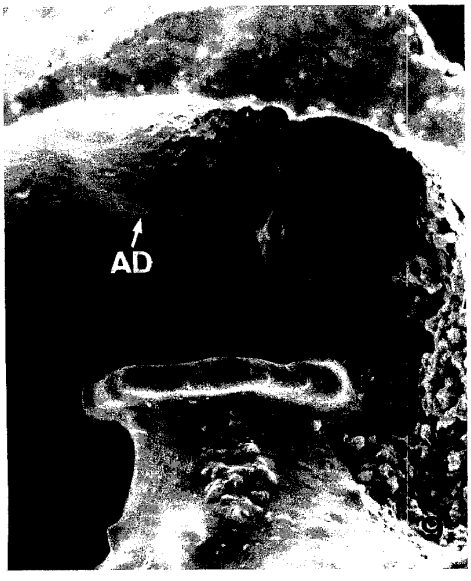
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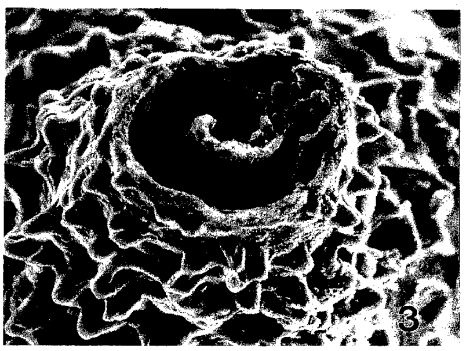
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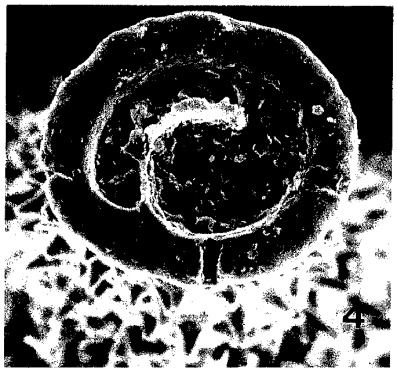
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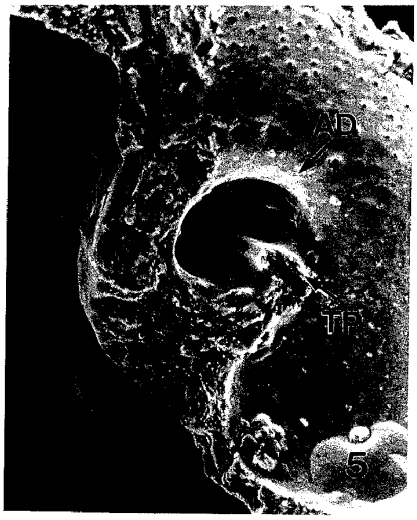
AD
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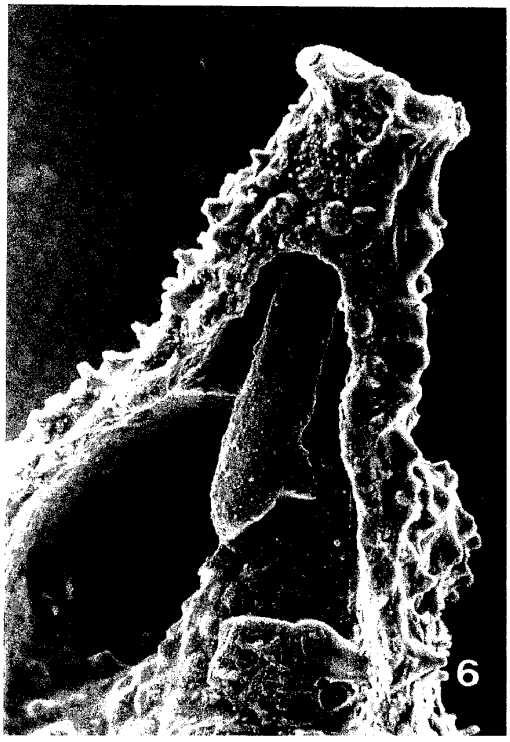
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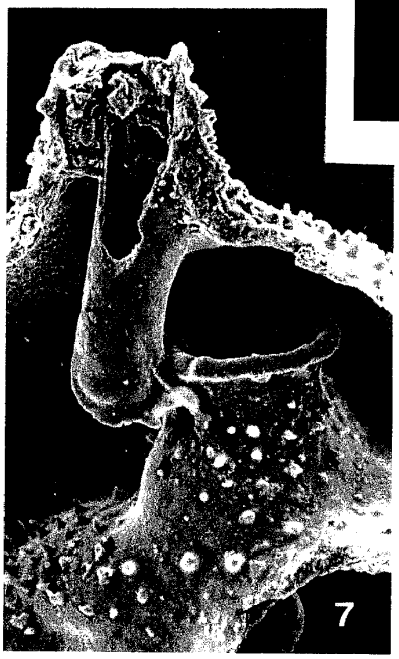
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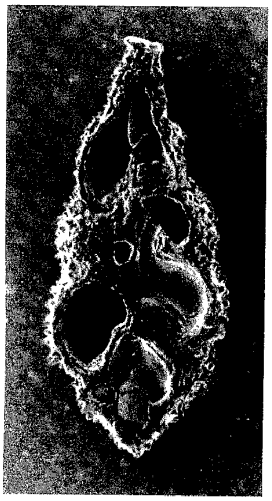

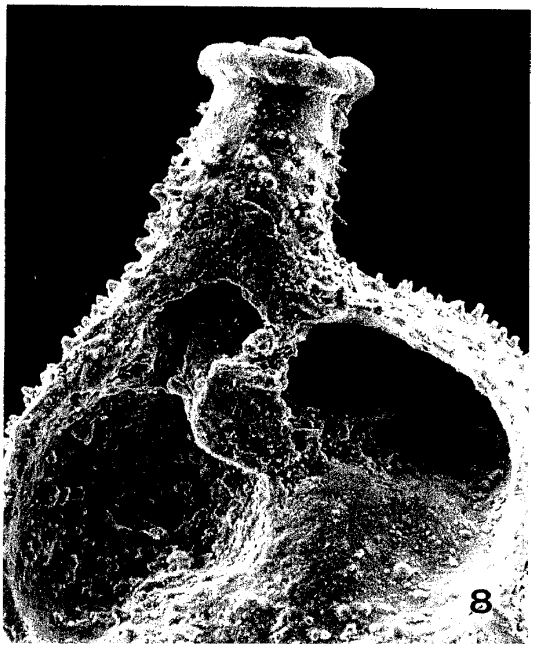
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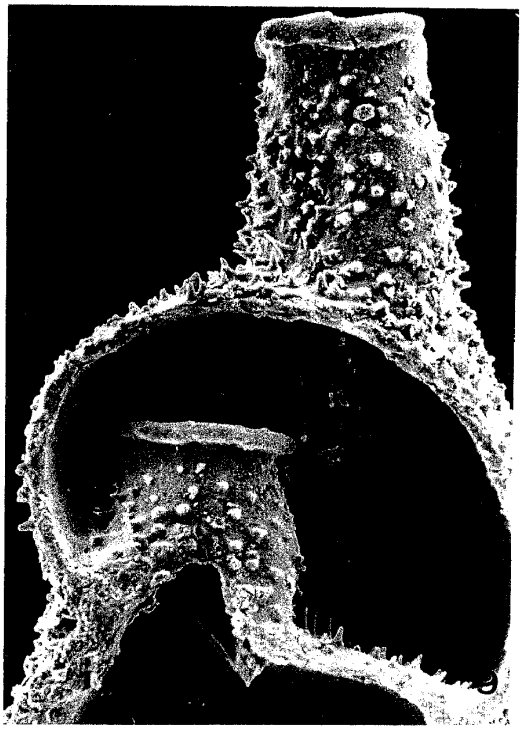
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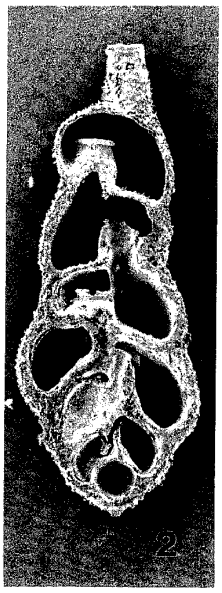
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Plate 32

(All figures are scanning electron micrographs)

Figs. 1, 3, 6. *Neouvigerina setosa* Jung, n. sp.

1. Sectioned specimen, showing internal structure. ×120.
3. Apertural view of lip-removed specimen, showing deeply folded toothplate which continues to the wall of apertural neck and forms a spirality. ×850.
6. Details of Fig. 1, showing that shovel-shaped toothplate embraces preceding apertural neck. ×580.

Figs. 2, 8, 9. *Neouvigerina auberiana ampullacea* (Brady)

2. Sectioned specimen, showing internal structure. ×80.
8. Sectioned specimen, showing toothplate attached to preceding apertural neck. ×380.
9. Details of Fig. 2, showing that toothplate is attached to the border of preceding apertural lip with two points. ×380.

Figs. 4, 5, 7. *Neouvigerina proboscidea* (Schwager)

4. Apertural view, showing well-developed lip and folded toothplate. ×580.
5. Fractured specimen, showing inside view. Note that the folded part of neck wall forms toothplate (TP) and that inflated and imperforate andoanulus (AD) is well developed. ×580.
7. Sectioned specimen, showing that toothplate is attached to preceding apertural neck and folded against the side of preceding one. ×380.

Plate 33

(All figures are scanning electron micrographs)

Figs. 1, 2, 4, 9, 12. *Euuvigerina akitaensis* (Asano)

1. Outer surface of penultimate chamber, showing pores and heavily sutured aspect. Note that areas around pores are compacted and not sutured. Sample KT 85-6, G-3, water depth 495 m, Enshu-nada. ×3,850.
2. Outer surface of penultimate chamber, showing ovate to elongate pores and granular aspect. Note that granules are more compactly aggregated around pores. Sample ST 802, GC P109, water depth 930 m, Okhotsk Sea. ×3,850.
4. Outer surface of antepenultimate chamber, showing circular to triangular pores and sutured boundaries depressed. CU : crystal unit. Sample SW-5, Sawane Formation, Sado Island. ×3,850.
9. Outer surface of penultimate chamber, showing subcircular to ovate pores and relatively smooth aspect. Note that smaller and more circular pores (PP) are seen below larger openings. Sample st. 144, water depth 360 m, Toyama Bay. ×3,850.
12. Etched outer surface of antepenultimate chamber, showing elongate pore tubules (PP) within crater-shaped domes. Sample SA-41, Kitaura Formation, Sarukawa, Oga Peninsula, Akita Prefecture. ×1,600.

Figs. 3, 11. *Euuvigerina juncea* (Cushman and Todd)

3. Outer surface of penultimate chamber, showing circular pore within crystal unit (CU) bounded by mosaic sutures. Sample 86052317, Chonan Formation, Boso Peninsula, Chiba Prefecture. ×3,850.
11. Inner surface of penultimate chamber, showing circular pores within crystal units (CU). Sample 86052316, Chonan Formation, Boso Peninsula, Chiba Prefecture. ×3,850.

Fig. 5. *Euuvigerina shiwoensis* (Asano)

Outer surface of antepenultimate chamber, showing elevated pores by dome developments near the suture of test. Sample 86052422, Iwasaka Formation, Boso Peninsula, Chiba Prefecture. ×3,850.

Fig. 6. *Euuvigerina kiyoshiasanoi* Jung, n. sp.

Outer surface of ultimate chamber, showing depressed pores below the surface. Sample st. 143, water depth 253 m, Toyama Bay. ×3,850.

Fig. 7. *Euuvigerina hispidocostata* (Cushman and Todd)

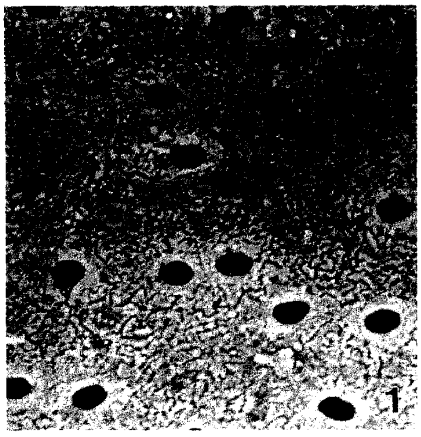
Outer surface of early portion, showing slit-like pores and sutured aspect. Note that compactly aggregated granules construct marginal areas of pores. Sample OK-1, Yonahama Formation, Okinawa. ×3,850.

Fig. 8. *Euuvigerina aculeata* (d'Orbigny)

Outer surface of early portion, showing slit-like pores and smooth aspect. Note that circular pores (PP) are seen below slit-like pores. Sample KT 85-6, G-8, water depth 587 m, Enshu-nada. ×3,850.

Fig. 10. *Euuvigerina* (*Hopkinsina*) *wakimotoensis* (Asano)

Inner surface of antepenultimate chamber, showing circular and depressed pores and smooth inner veneer. Note that sutural lines below inner veneer stand out in relief. Sample AN-15, Wakimoto Formation, Anden, Oga Peninsula, Akita Prefecture. ×3,850.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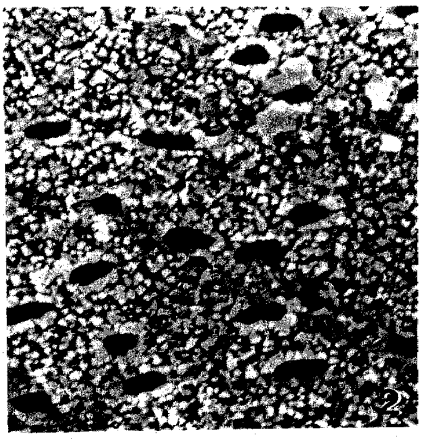
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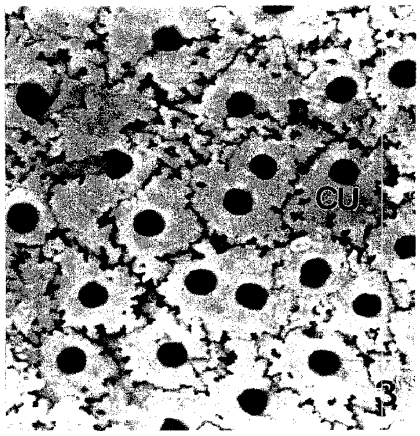
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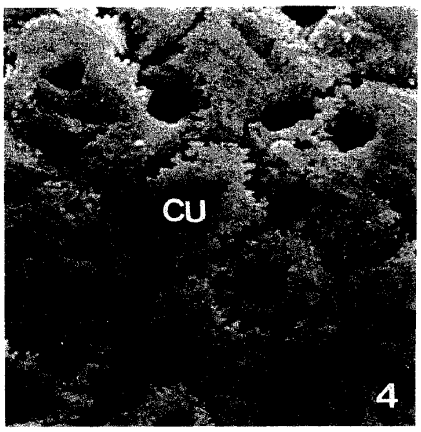
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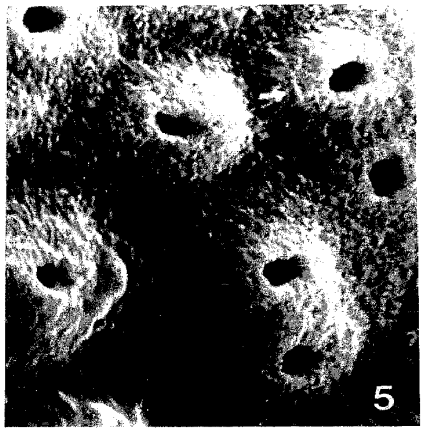
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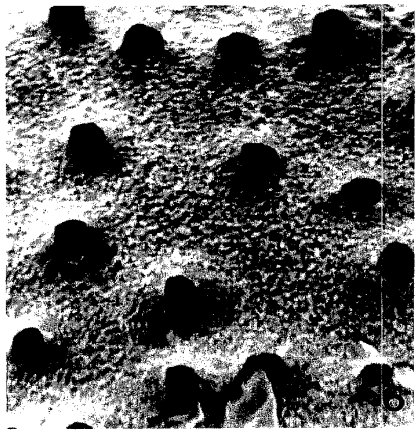
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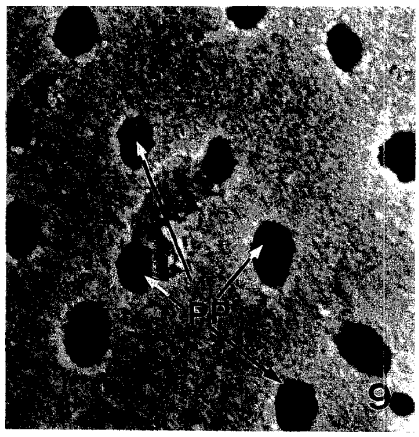
7


PP
8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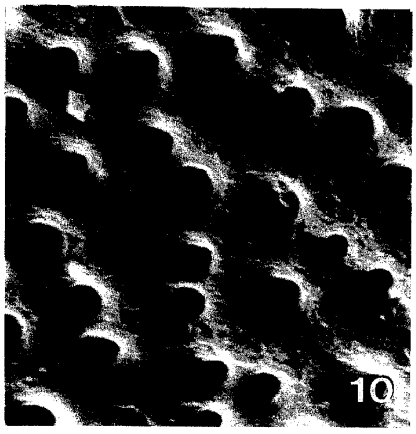
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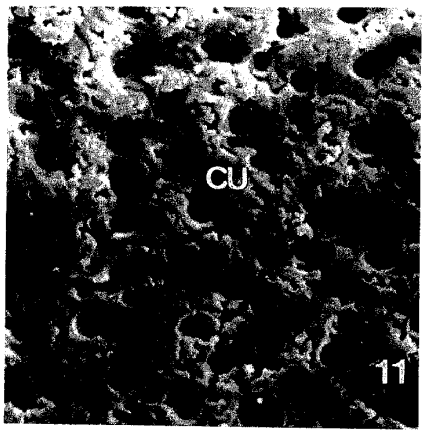
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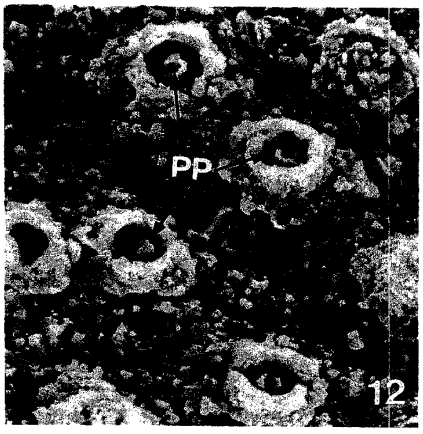
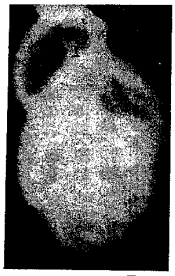

PP
12


1a


1b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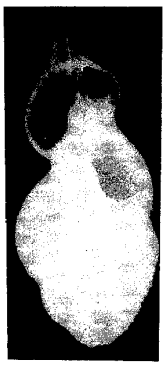
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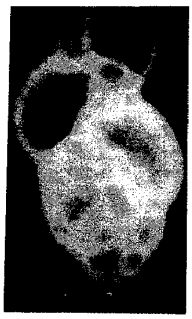
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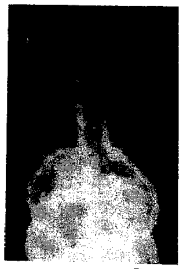
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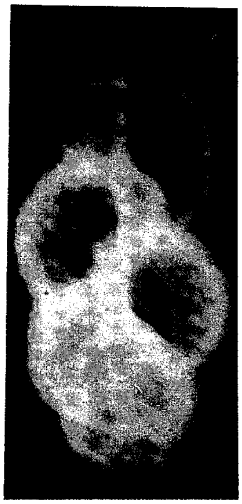
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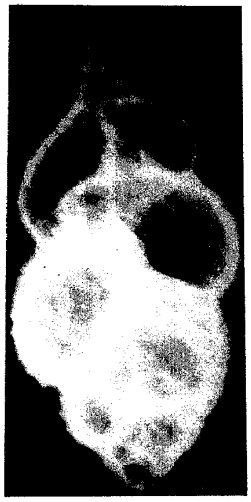
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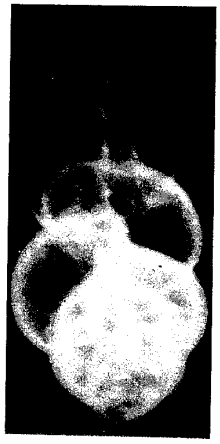
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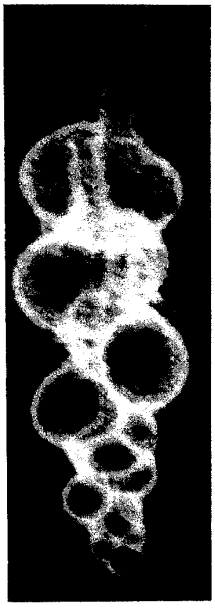
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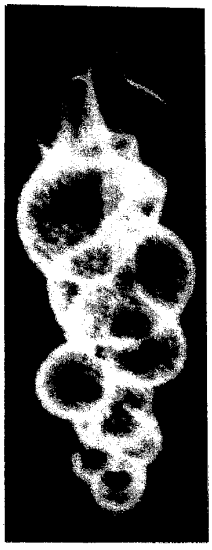
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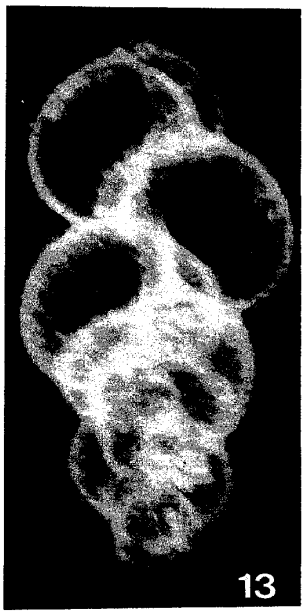
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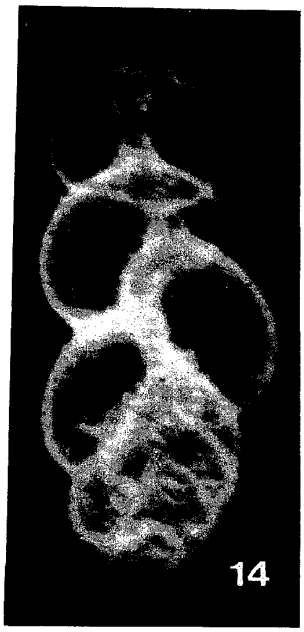
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Plate 34

(All figures are microradiographs)

Figs. 1–3. *Neouvigerina auberiana ampullacea* (Brady)
All megalospherics. Sample OK-2, middle part of Yonabaru Formation, Okinawa. ×77.

Fig. 4. *Neouvigerina pseudoampullacea* (Asano)
Megalospherics. Sample KT 85–6, G-2, water depth 938 m, Enshu-nada. ×77.

Figs. 5, 6. *Neouvigerina setosa* Jung, n. sp.
5. Megalospherics. 6. Microspherics.
Sample G-77, upper part of Ooura Formation, Miyako-jima. ×154.1

Figs. 7, 8. *Neouvigerina proboscidea vadescens* (Cushman)
7. Megalospherics. Sample TS-6, water depth 825 m, Tosa Bay. ×154.
8. Microspherics. Sample KT 81-15, G-6, water depth 410 m, Kii- suido. ×154.

Figs. 9, 10. *Neouvigerina proboscidea* (Schwager)
Both megalospherics. Sample KT 85–6, G-8, water depth 587 m, Enshu-nada. ×77.

Figs. 11, 12. *Neouvigerina interrupta* (Brady)
11. Microspherics. 12. Megalospherics.
Sample TS-6, water depth 825 m, Tosa Bay. ×154.

Figs. 13, 14. *Euuvigerina* (*Hopkinsina*) *shinboi* (Matsunaga)
13. Microspherics. 14. Megalospherics.
Sample NSG-3, middle part of Sugata Formation, Himi. ×154.

Plate 35

(All figures are microradiographs)

Figs. 1, 2. *Euuvigerina schencki* (Asano)
Both megalospherics. Sample GH 85-2, st. 15, water depth 97 m, off Shimonoseki. ×77.

Figs. 3, 4. *Euuvigerina kiyoshiasanoi* Jung, n. sp.
3. Megalospherics. 4. Microspherics.
Sample st. 122, water depth 241 m, Toyama Bay. ×77.

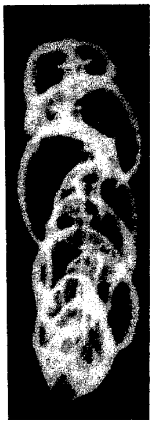
Figs. 5, 10. *Euuvigerina introrsa* Jung, n. sp.
5. Megalospherics. Sample OK-19, Shinzato Formation, Okinawa. ×77.
10. Microspherics. Sample OM-13, Takanabe Member, Koyu Formation, Miyazaki Prefecture. ×77.

Figs. 6, 7. *Euuvigerina nipponica* Jung, n. sp.
Both megalospherics. Sample TS-7, water depth 918 m, Tosa Bay. ×77.

Figs. 8, 9. *Euuvigerina lobulata* Jung, n. sp.
8. Microspherics. 9. Megalospherics.
Sample st. 104, water depth 450 m, Toyama Bay. ×77.

Figs. 11, 12. *Euuvigerina hispida* (Schwager)
11. Microspherics. Sample TS-7, water depth 918 m, Tosa Bay. ×77.
12. Megalospherics. Sample KT 81-15, G-10, water depth 1,107 m, Kii-suido. ×77.

Figs. 13, 14. *Euuvigerina shiwoensis* (Asano)
13. Megalospherics. Sample KT 81-6, G-8, water depth 587 m, Enshu-nada. ×63.
14. Megalospherics. Sample 86050422, Iwasaka Formation, Boso Peninsula, Chiba Prefecture. ×63.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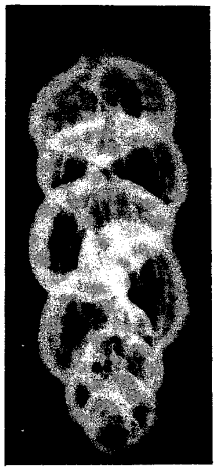
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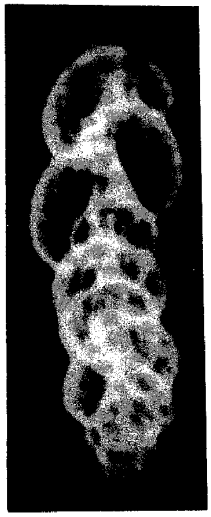
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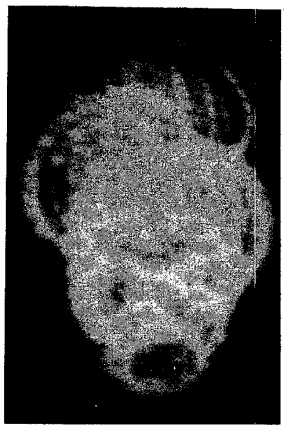
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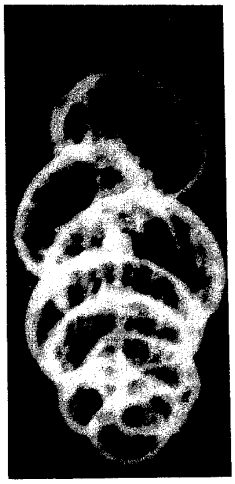
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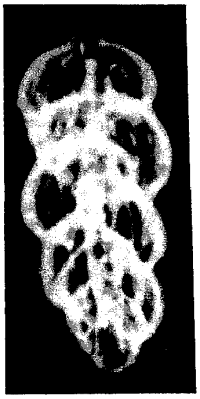
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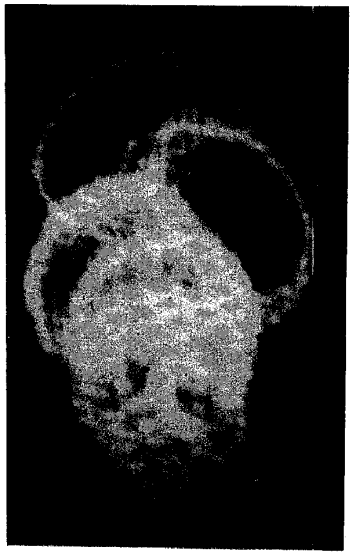
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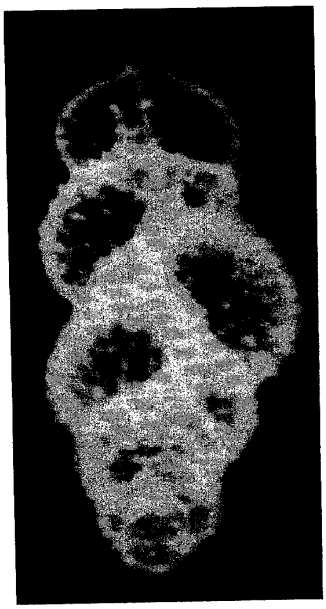
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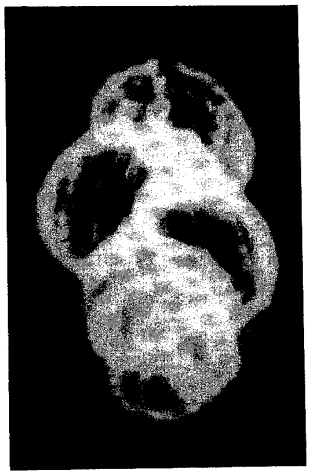
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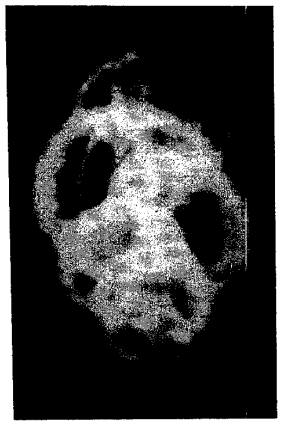
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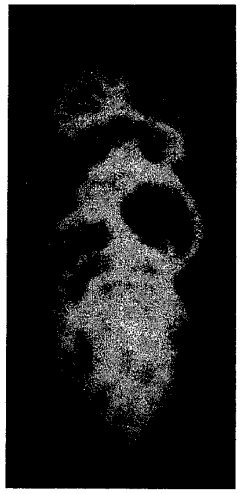
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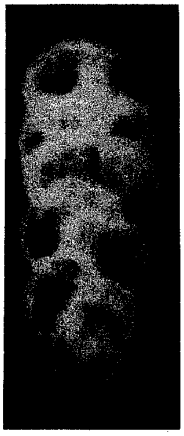
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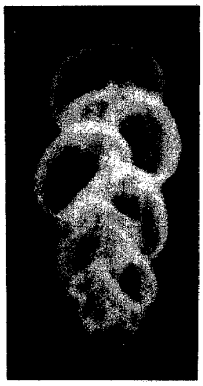
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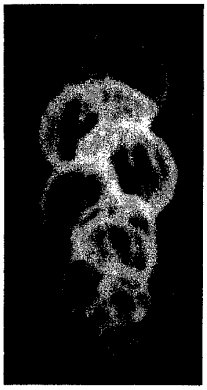
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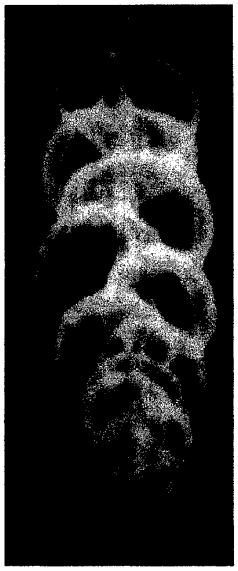
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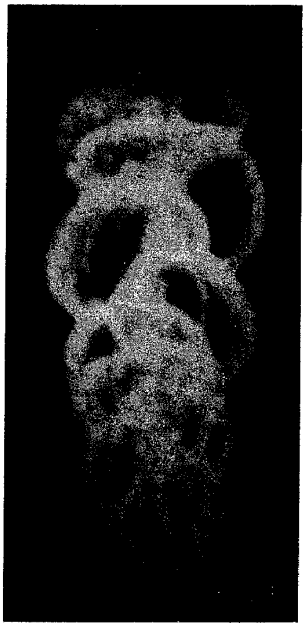
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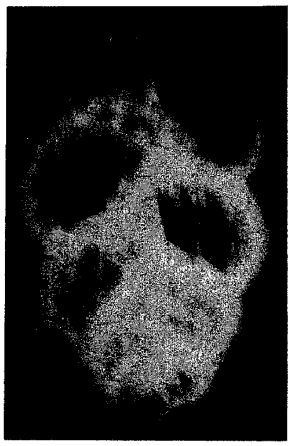
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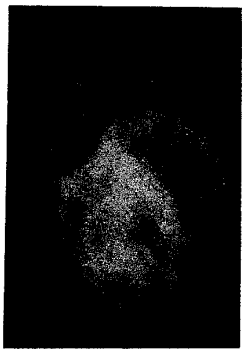
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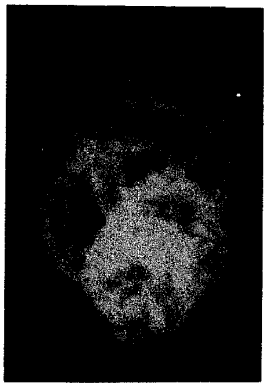
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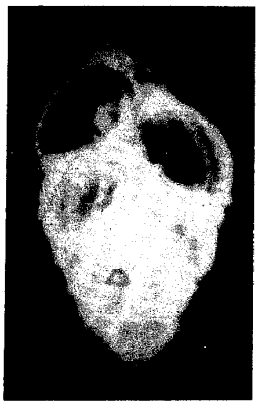
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Plate 36

(All figures are microradiographs)

Figs. 1-5. *Euuvigerina akitaensis* (Asano)

1. Microspherics. 2-5. Megalospherics. All ×63.

1, 2. Sample OB8528-2, Wakimoto Formation, Oibanazaki, Oga Peninsula, Akita Prefecture.

3, 4. Sample Tau-12, upper part of Uchisugawa Formation, Kita-kanbara, Niigata Prefecture.

5. Sample GH 76-3-II-15, water depth 925 m, off Hachinohe.

Figs. 6, 7. *Euuvigerina akitaensis grandis* Jung, n. subsp.

6. Megalospherics. 7. Microspherics.

Sample OB-22-U, Kitaura Formation, west of Oibanazaki, Oga Peninsula, Akita Prefecture. ×63.

Fig. 8. *Euuvigerina aculeata* (d'Orbigny)

Megalospherics. Sample TS-7, water depth 918 m, Tosa Bay. ×63.

Fig. 9. *Euuvigerina hispidocostata* (Cushman and Todd)

Megalospherics. Sample OK-1, middle part of Yonabaru Formation, Okinawa. ×77.

Fig. 10. *Euuvigerina flintii* (Cushman)

Megalospherics. OK-1, middle part of Yonabaru Formation, Okinawa. ×77.

Figs. 11, 12. *Euuvigerina* sp. A

11. Megalospherics. 12. Microspherics.

Sample HE-4, Kawabaru Member, Saito Formation, Kawaminami-cho, Koyu-gun, Miyazaki Prefecture. ×77.

Figs. 13, 14. *Euuvigerina curticosta* (Cushman)

13. Megalospherics. 14. Microspherics.

Sample IA-5, Aya Member, Higashimorogata Formation, Aya-cho, Higashimorogata-gun, Miyazaki Prefecture. ×63.

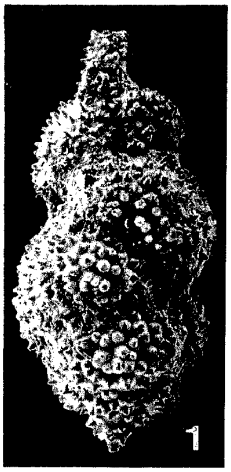
Plate 37

(All figures are scanning electron micrographs)

Figs. 1–7. *Neouvigerina setosa* Jung, n. sp.
1. Holotype, IGPS 99857 ; 2–5. Paratypes, IGPS 99858–99861.
All from sample G-77, upper part of Ooura Formation, Miyako-jima. ×120.
6. Details of pores in penultimate chamber of Fig. 5. ×3,850.
7. Details of ornamentation of Fig. 1. ×580.

Figs. 8–11. *Neouvigerina proboscidea vadescens* (Cushman)
8, 9. IGPS 99854, 99855. Sample TS-6, water depth 825 m, Tosa Bay. ×120.
10. Details of pores in penultimate chamber of Fig. 8. ×1,600.
11. Details of ornamentation of Fig. 9. ×580.

Figs. 12–17. *Neouvigerina takayanagii* Jung, n. sp.
14. Holotype, IGPS 99864 ; 12, 13, 15. Paratypes, IGPS 99862, 99863, 99865.
12, 14. Sample TS-6, water depth 825 m, Tosa Bay. ×120.
13. Sample KT 81-15, G-6, water depth 410 m, Kii-suido. ×120.
15. Sample KT 85-6, G-4, water depth 187 m, Enshu-nada. ×120.
16. Details of wall surface in middle portion of Fig. 12. ×1,600.
17. Details of ornamentation in middle portion of Fig. 14. ×580.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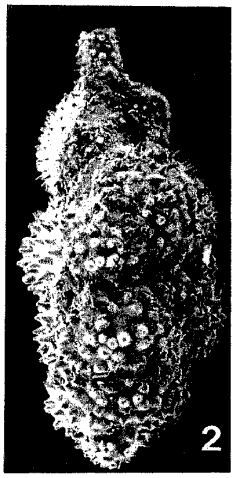
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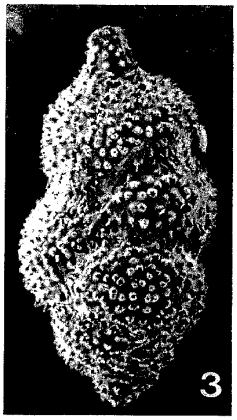
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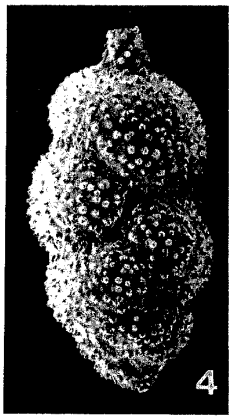
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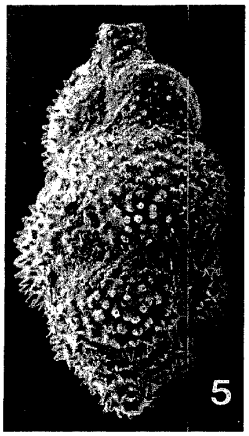
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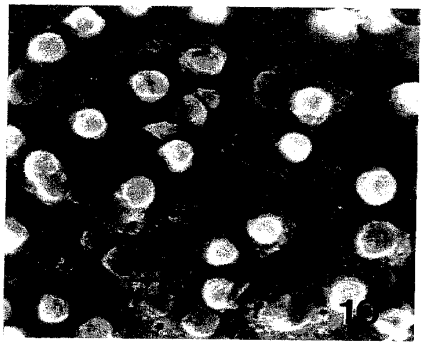
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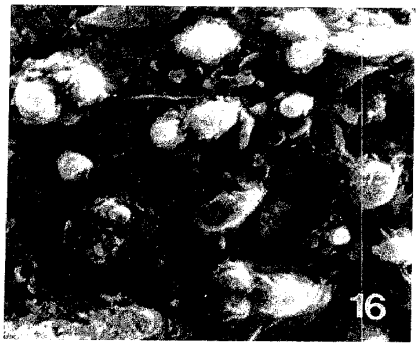
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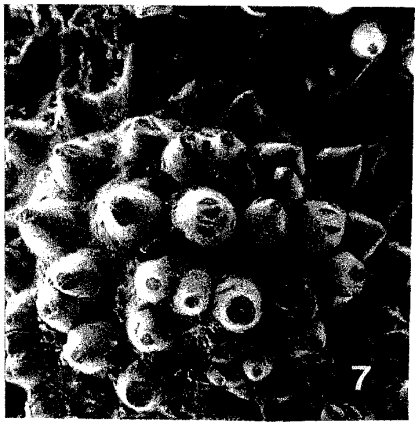
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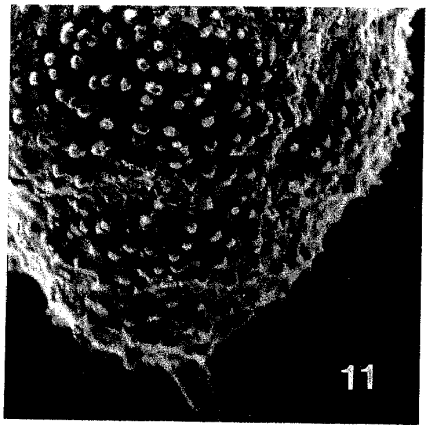
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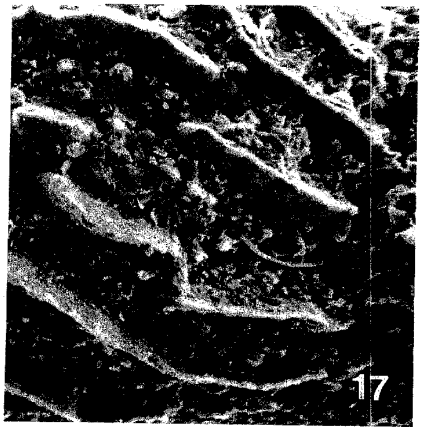
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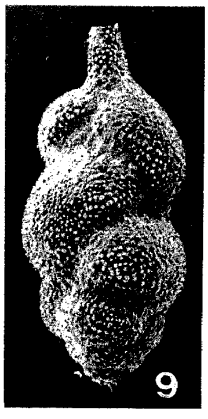
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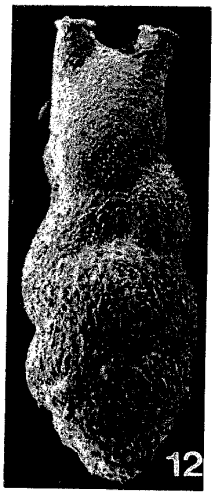
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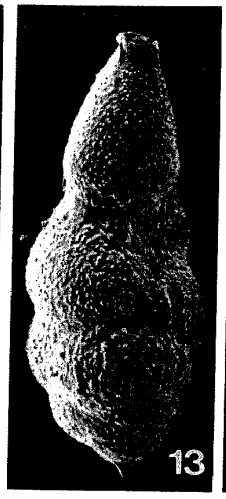
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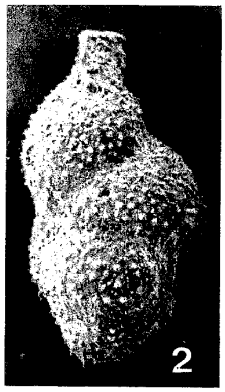
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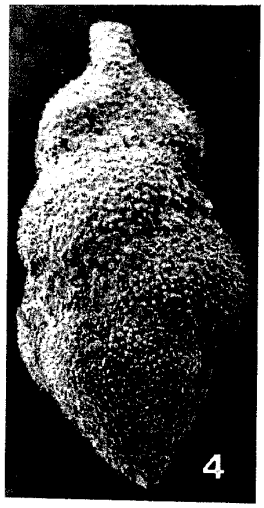
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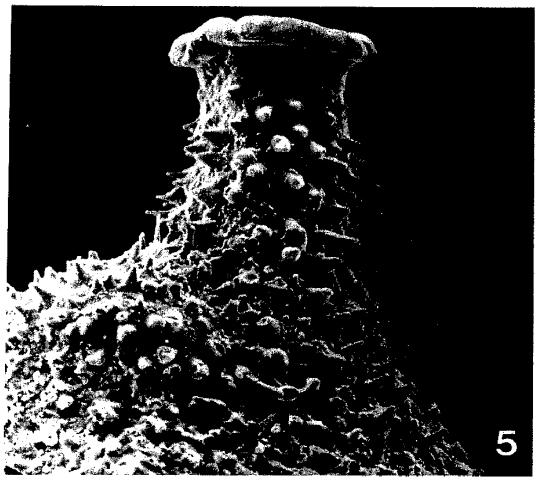
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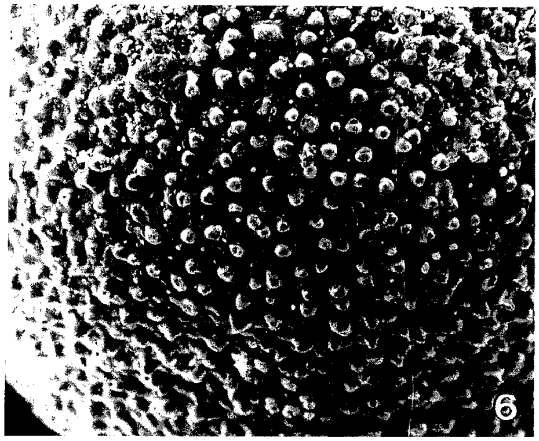
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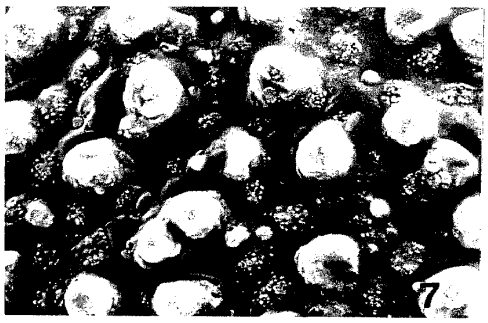
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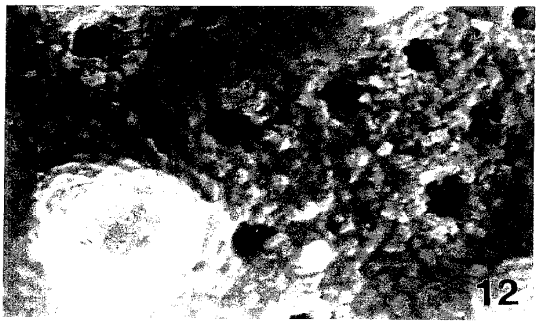
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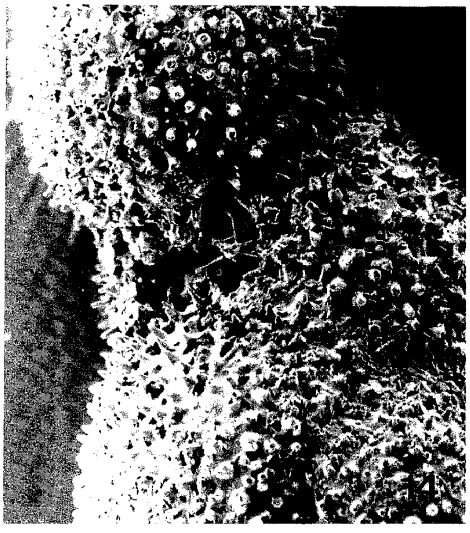
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Plate 38

(All figures are scanning electron micrographs)

Figs. 1–7. *Neouvigerina proboscidea* (Schwager)

1, 2. IGPS 99850, 99851. Sample KT 85-6, G-8, water depth 587 m, Enshu-nada. ×80.

3, 4. IGPS 99852, 99853. Sample OK-14, upper part of Yonabaru Formation, Okinawa. ×80.

5. Details of ornamentation of Fig. 1. ×380.

6. Details of ornamentation of Fig. 4. ×380.

7. Details of wall surface of Fig. 4. ×1,200.

Figs. 8, 9. *Neouvigerina pseudoampullacea* (Asano)

8. IGPS 99856. Sample KT 85-6, G-1, water depth 1,406 m, Enshu-nada. ×120.

9. Details of wall surface of Fig. 8. ×1,200.

Figs. 10–14. *Neouvigerina auberiana ampullacea* (Brady)

10. IGPS 99845. Sample No. 1, Uebaru Formation, Okinawa. ×80.

11. IGPS 99846. Sample OK-2, middle part of Yonabaru Formation, Okinawa. ×80.

12. Details of pores for the early portion of uncatalogued specimen in the IGPS collection. ×2,500.

13. Details of wall surface of Fig. 10. ×1,200.

14. Details of ornamentation of Fig. 11. ×170.

Plate 39

(All figures are scanning electron micrographs)

Figs. 1–5. *Neouvigerina interrupta* (Brady)

1–3. IGPS 99847–99849. Sample TS-6, water depth 825 m, Tosa Bay. ×120.

4. Details of ornamentation of Fig. 2. ×380.

5. Details of wall surface of Fig. 2. ×1,600.

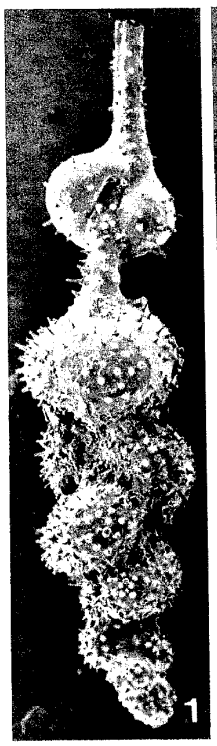
Figs. 6–13. *Euuvigerina* (*Hopkinsina*) *shinboi* (Matsunaga)

6–8. IGPS 99836–99838. Sample NA-1, Nanatani Formation, Minami-kanbara, Niigata Prefecture. ×120.

9–11. IGPS 99839–99841. Sample NSG-3, middle part of Sugata Formation, Himi. ×120

12. Details of ornamentation of Fig. 6. ×580.

13. Details of pores in ultimate chamber of uncatalogued specimen in the IGPS collection. ×3,850.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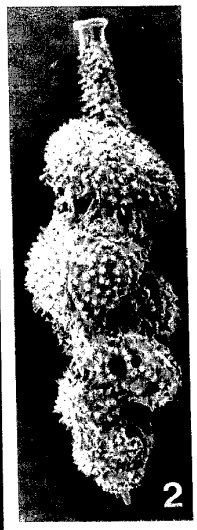
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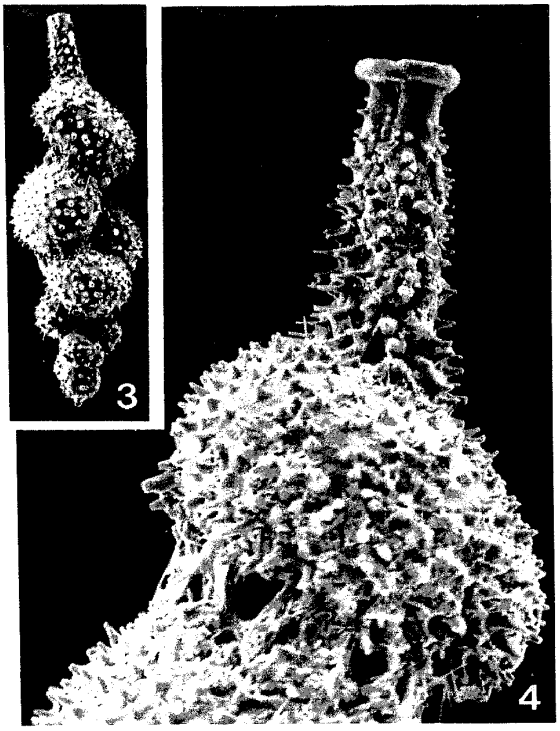
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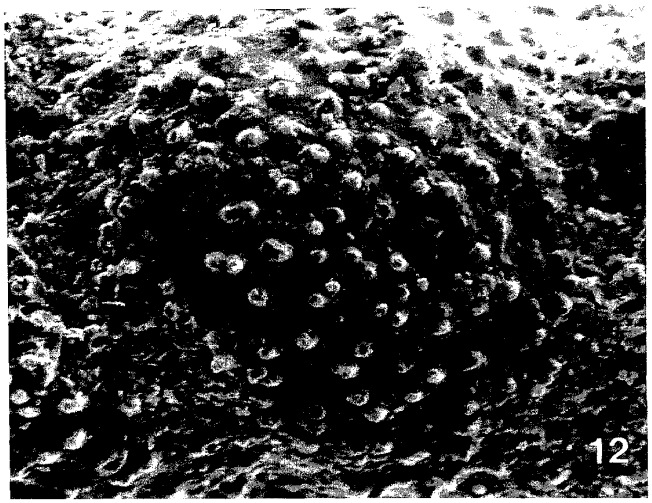
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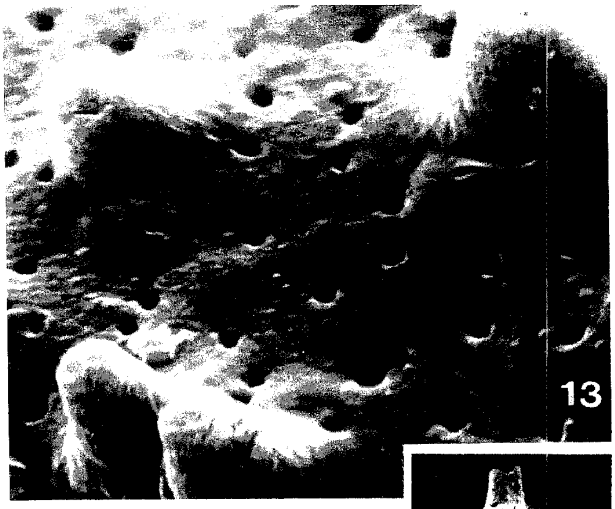
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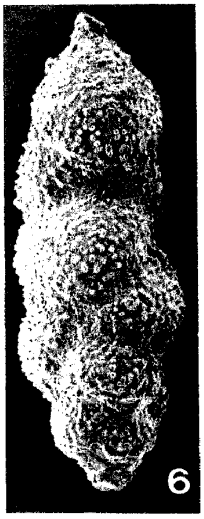
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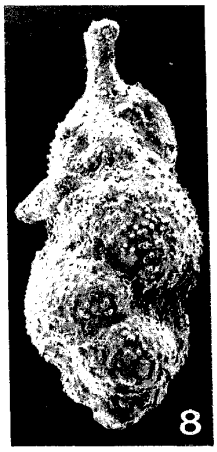
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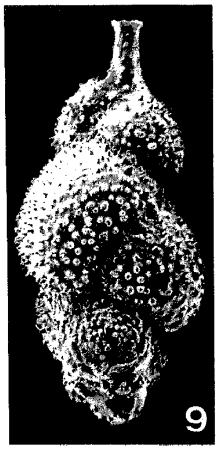
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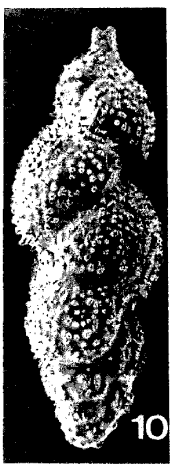
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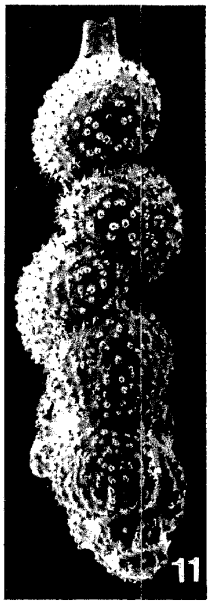
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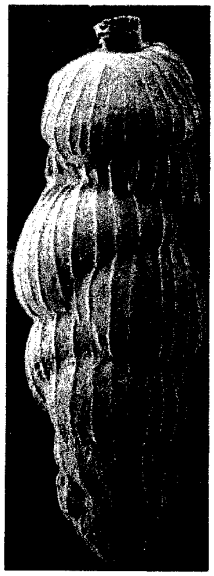

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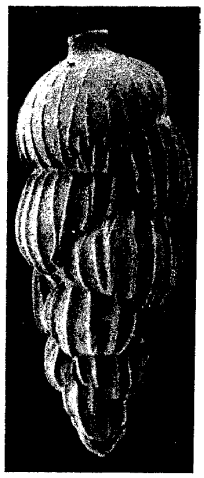

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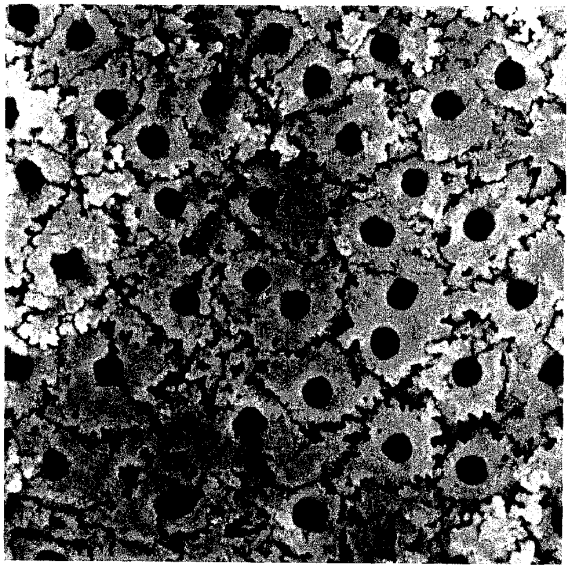

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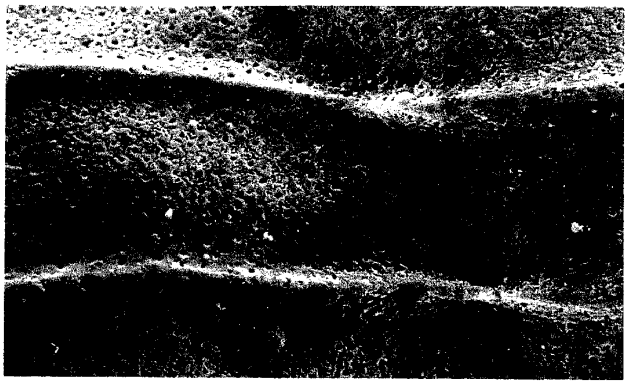

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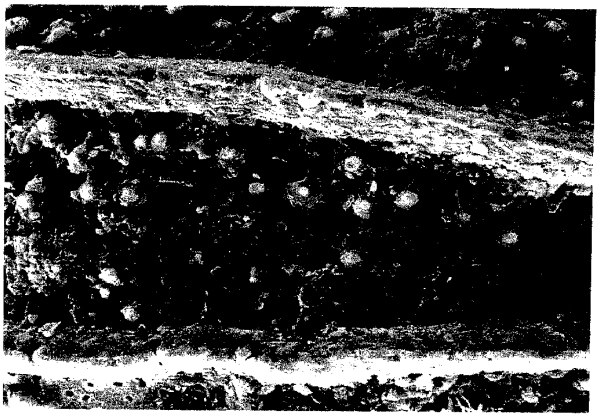

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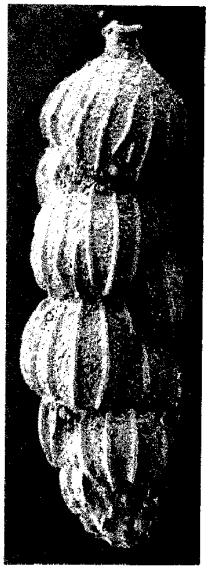

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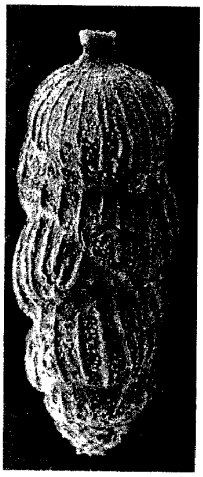

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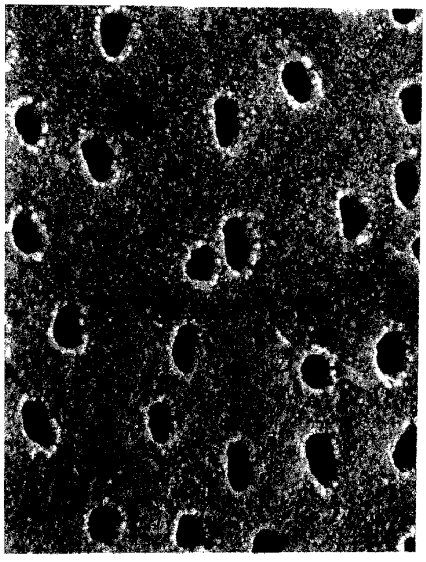

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Plate 40

(All figures are scanning electron micrographs)

Figs. 1–5. *Euuvigerina juncea* (Cushman and Todd)

1–3. IGPS 99796–99798. Sample 86052317, Chonan Formation, Boso Peninsula, Chiba Prefecture. ×80.

4. Details of pores and 'jigsaw-puzzle pattern' in penultimate chamber of Fig. 1. ×3,850.

5. Details of ornamentation of Fig. 2. ×850.

Figs. 6–11. *Euuvigerina kiyoshiasanoi* Jung, n. sp.

6, 7. Paratypes, IGPS 99799, 99800. Sample st. 143, water depth 253 m, Toyama Bay. ×80.

8. Holotype, IGPS 99801. Sample KT 85–15, G-1, water depth 335 m, Yamato Bank. ×80.

9. Paratype, IGPS 99802. Sample ASH-3, Junicho Formation, Himi. ×80.

10. Details of ornamentation of Fig. 6. ×850.

11. Details of pores for early portion of Fig. 7. ×3,850.

Plate 41

(All figures are scanning electron micrographs)

Figs. 1–4. *Euuvigerina akitaensis grandis* Jung, n. subsp.

1. Holotype, IGPS 99774; 2. Paratype, IGPS 99775. Both from sample OB22-U, Kitaura Formation, west of Oibanazaki, Oga Peninsula, Akita Prefecture. ×80.
3. Details of pores in ultimate chamber of Fig. 2. ×3,850.
4. Details of ornamentation of Fig. 2. ×380.

Figs. 5–10. *Euuvigerina akitaensis* (Asano)

5, 6. IGPS 99770, 99771. Sample OB8528-2, Wakimoto Formation, Oibanazaki, Oga Peninsula, Akita Prefecture. ×80.

7. Details of pores on ultimate chamber of Fig. 5. ×3,850.
8. Details of ornamentation of Fig. 6. ×380.
9. IGPS 99772. Sample st. 144, water depth 360 m, Toyama Bay. ×80.
10. IGPS 99773. Sample 86052207, Umegase Formation, Boso Peninsula, Chiba Prefecture. ×80.

Figs. 11–13. *Euuvigerina akitaensis pumila* Jung, n. subsp.

11. Holotype, IGPS 99776. Sample 86052208, Umegase Formation, Boso Peninsula, Chiba Prefecture. ×80.
12. Details of ornamentation of Fig. 11. ×380.
13. Details of pores in antepenultimate chamber of Fig. 11. ×3,850.


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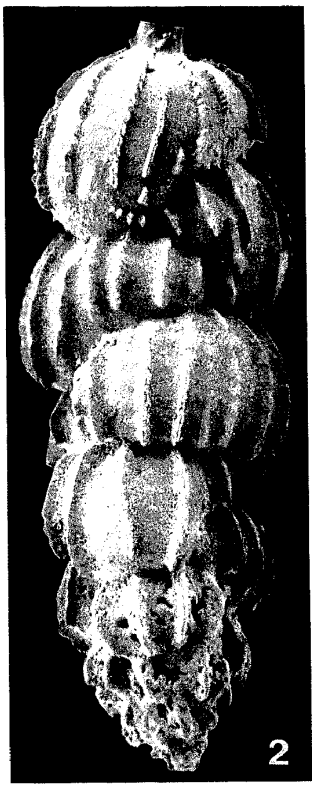
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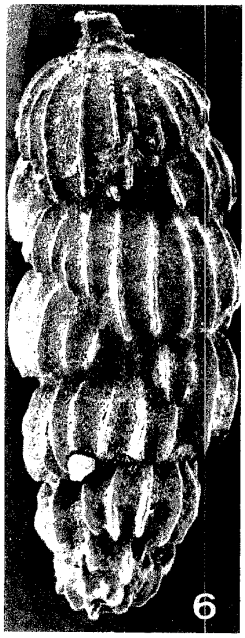
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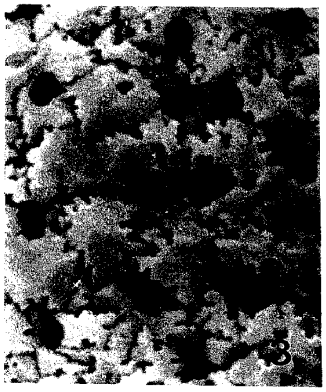
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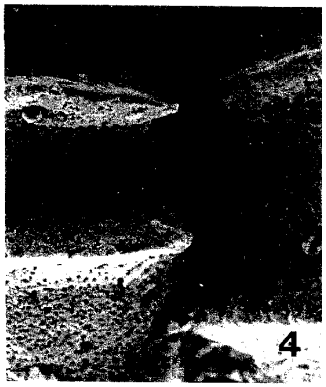
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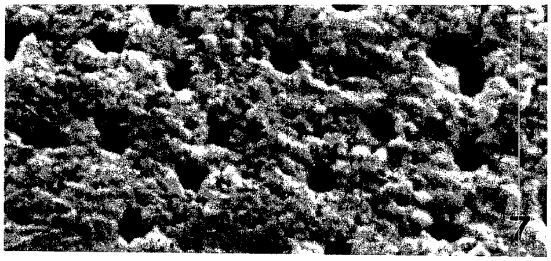
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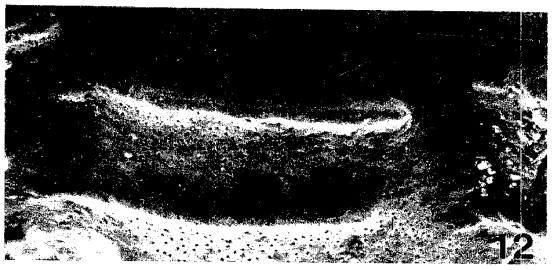
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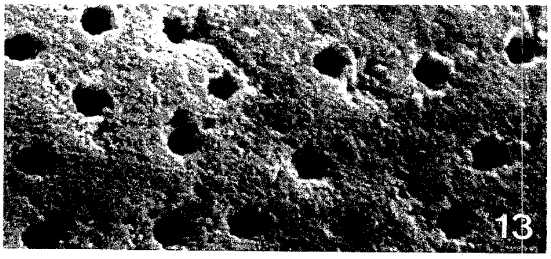
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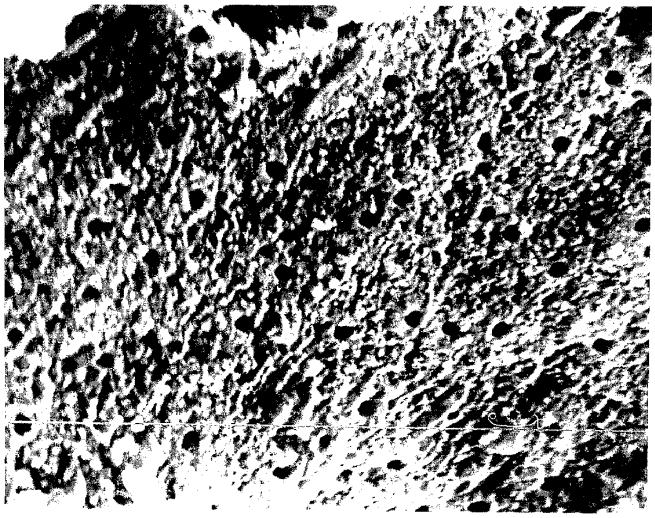
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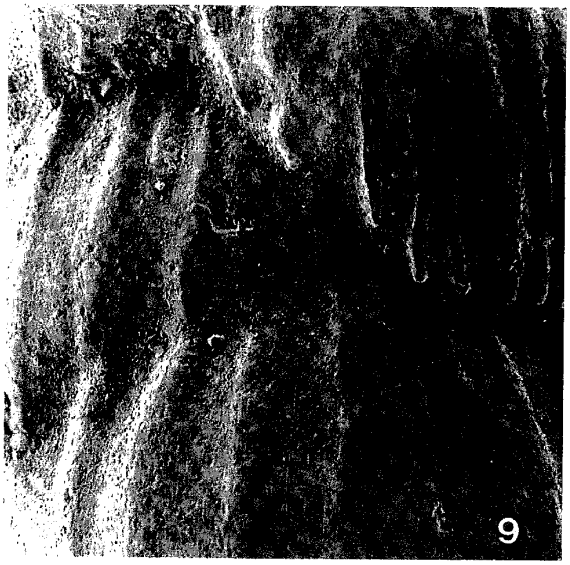
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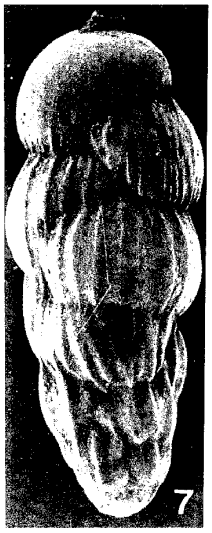
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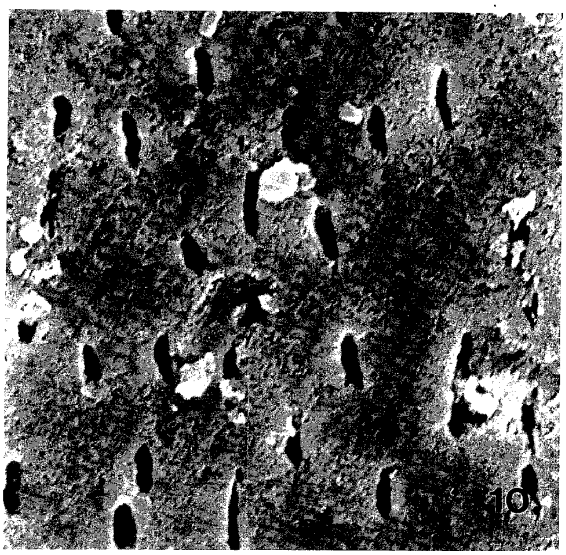
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Plate 42

(All figures are scanning electron micrographs)

Figs. 1–5. *Euuvigerina* (*Hopkinsina*) *wakimotoensis* (Asano)

1–3. IGPS 99842–99844. Sample AN-15, Wakimoto Formation, Anden, Oga Peninsula, Akita Prefecture. ×80.

4. Details of ornamentation of Fig. 3. ×380.

5. Details of pores in ultimate chamber of Fig. 1. ×3,850.

Figs. 6–10. *Euuvigerina yabei* (Asano)

6. IGPS 99828. Sample OB8527-6, Wakimoto Formation, Oibanazaki, Oga Peninsula, Akita Prefecture. ×57.

7, 8. IGPS 99829, 99830. Sample AN-35, Shibikawa Formation, Anden, Oga Peninsula, Akita Prefecture. ×250.

9. Details of ornamentation of Fig. 7. ×250.

10. Details of pores in antepenultimate chamber of uncatalogued specimen in the IGPS collection. ×3,850.

Plate 43

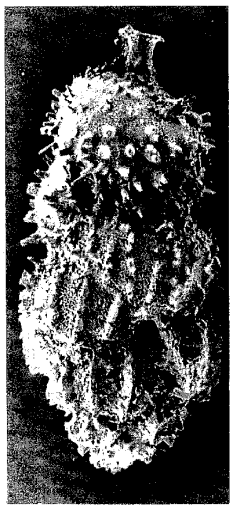
(All figures are scanning electron micrographs)

Figs. 1–9. *Euuvigerina lobulata* Jung, n. sp.

3. Holotype, IGPS 99805 ; 1, 2, 4–7. Paratypes, IGPS 99803, 99804, 99806–99809.
1–2. Sample st. 104, water depth 450 m, Toyama Bay. ×80.
3–5. Sample st. 87, water depth 345 m, Toyama Bay. ×80.
6–7. Sample YBT-10, lower part of Yabuta Formation, Himi. ×80.
8. Details of pores in ultimate chamber of Fig. 1. ×3,850.
9. Details of ornamentation of Fig. 2. ×380.

Figs. 10–15. *Euuvigerina schencki* (Asano)

10, 11. IGPS 99816, 99817. Sample KT 85-6, G-4, water depth 187 m, Enshu-nada. ×80.
12, 13. IGPS 99818, 99819. Sample GH 85-2, st. 215, water depth 97 m, off Shimonoseki. ×80.
14. Details of ornamentation of Fig. 12. ×580.
15. Details of pores in ultimate chamber of Fig. 11. ×3,850.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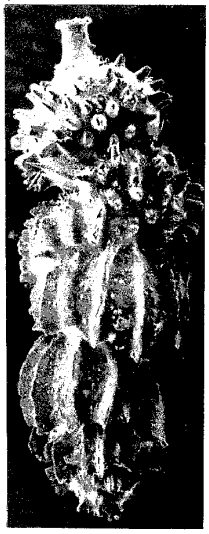
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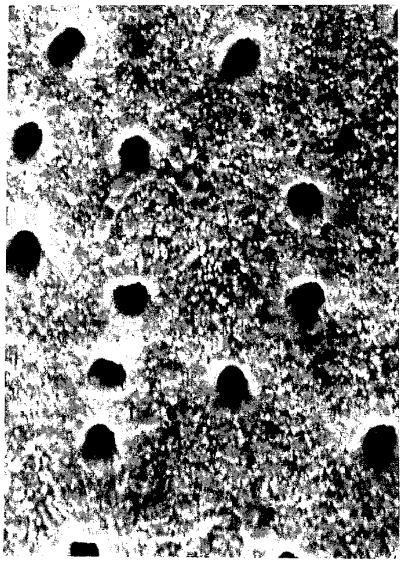
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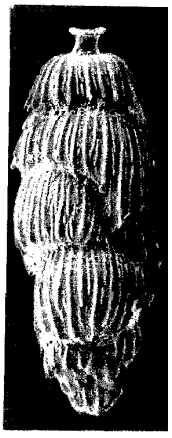
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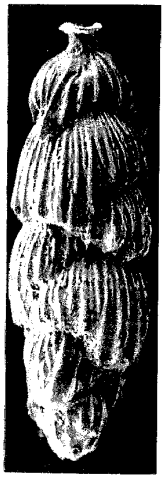
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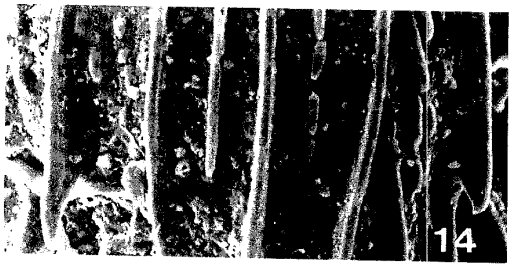
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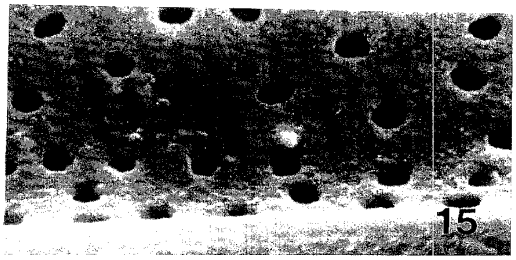
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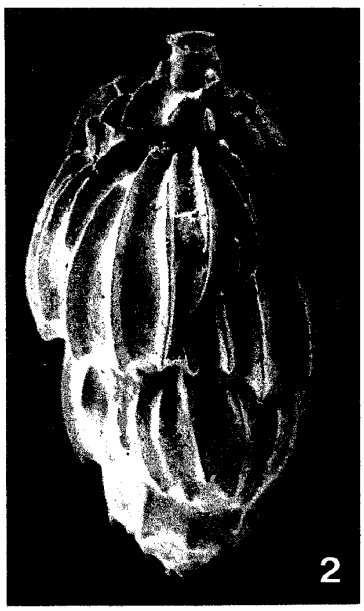
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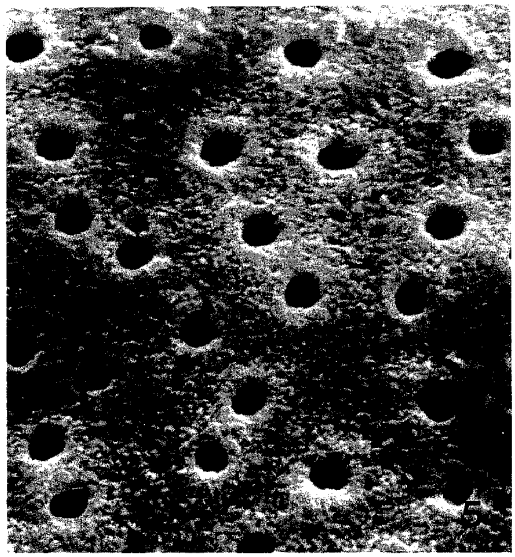


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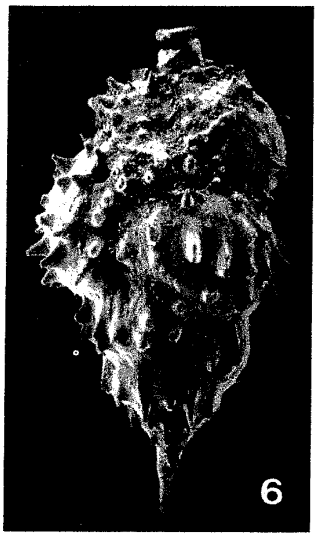
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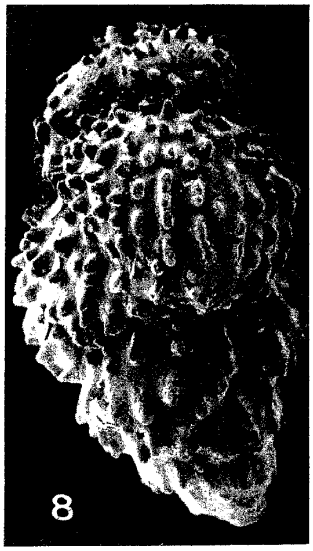
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Plate 44

(All figures are scanning electron micrographs)

Figs. 1–5. *Euuvigerina shiwoensis* (Asano)

1–2. IGPS 99824, 99825. Sample 86052422, Iwasaka Formation, Boso Peninsula, Chiba Prefecture. ×80.

3–4. IGPS 99826, 99827. Sample KT 85-6, G-8, water depth 587 m, Enshu-nada. ×80.

5. Details of pores in ultimate chamber of Fig. 1. ×3,850.

Figs. 6–10. *Euuvigerina aculeata* (d'Orbigny)

6–7. IGPS 99767, 99768. Sample KT 85-6, G-8, water depth 587 m, Enshu-nada. ×57.

8. IGPS 99769. Sample 86052422, Iwasaka Formation, Boso Peninsula, Chiba Prefecture. ×80.

9. Details of wall surface in ultimate chamber of Fig. 6. ×850.

10. Details of pores in ultimate chamber of Fig. 6. ×3,850.

Plate 45

(All figures are scanning electron micrographs)

Figs. 1–6. *Euuvigerina nipponica* Jung, n. sp.

1, 2. Paratypes, IGPS 99812, 99813. Sample KT 81-15, G-10, 1,107 m, Kii-suido. ×80.

3. Paratype, IGPS 99814. Sample KT 85-6, G-2, water depth 938 m, Enshu-nada. ×80.

4. Holotype, IGPS 99815. Sample TS-7, water depth 918 m, Tosa Bay. ×80.

5. Details of pores in ultimate chamber of Fig. 4. ×3,850.

6. Details of ornamentation of Fig. 1. ×250.

Figs. 7–12. *Euuvigerina curticosta* (Cushman)

7. IGPS 99777. Sample IA-5, Aya Member, Higashimorogata Formation, Aya-cho, Higashimorogata-gun, Miyazaki Prefecture. ×80.

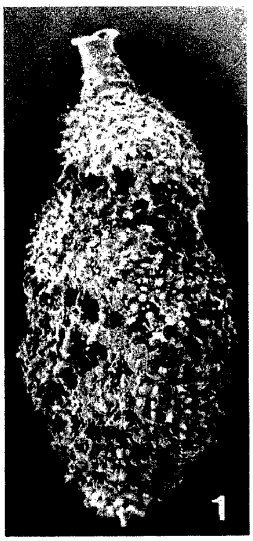
8. IGPS 99778. Sample OK-14, upper part of Yonabaru Formation, Okinawa. ×80.

9. IGPS 99779. Sample KT 81-15, G-1, water depth 410 m, Kii-suido. ×80.

10. IGPS 99780. Sample OM-13, Takanabe Member, Koyu Formation, Takanabe-cho, Koyu-gun, Miyazaki Prefecture. ×80.

11. Details of ornamentation of Fig. 10. ×250.

12. Details of pores in ultimate chamber of Fig. 8. ×3,850.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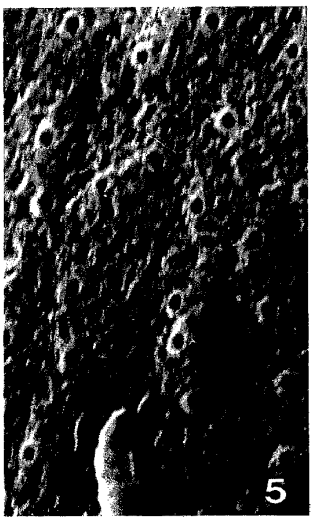
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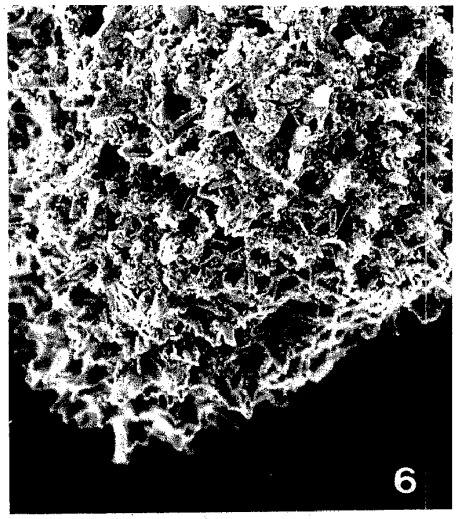
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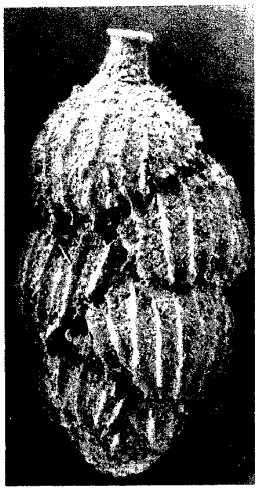

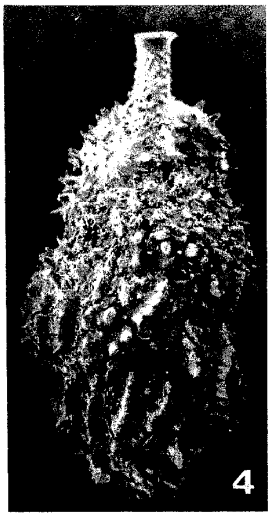
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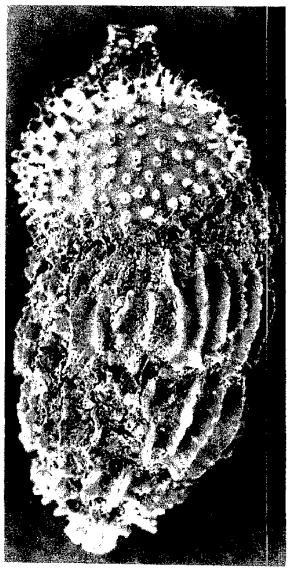

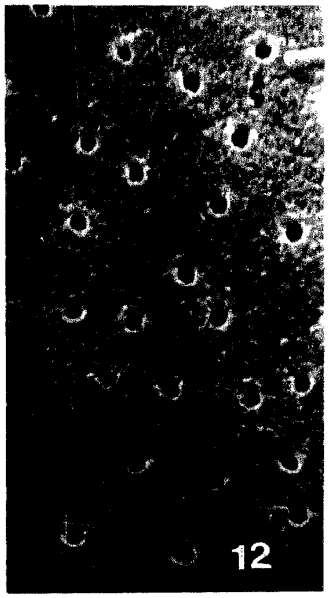
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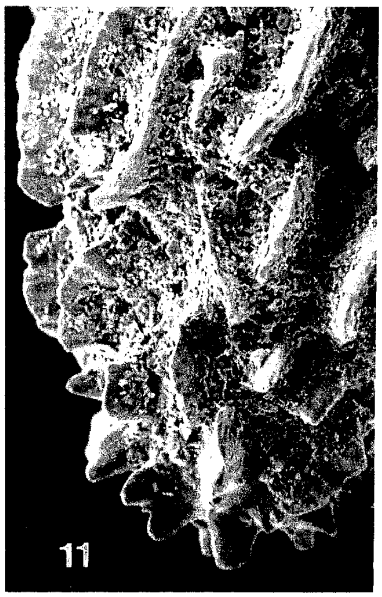
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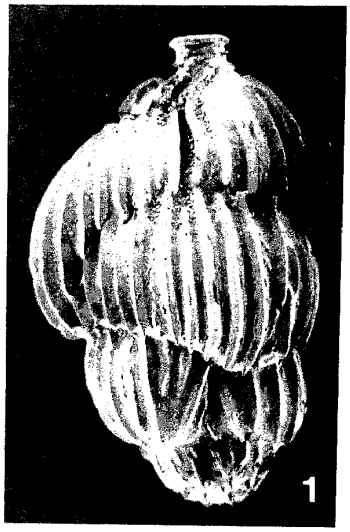
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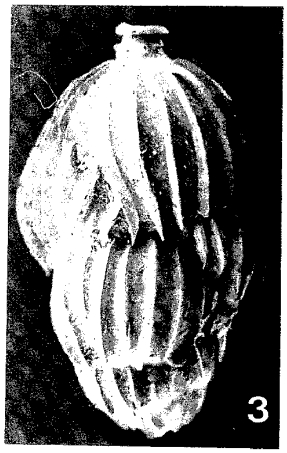
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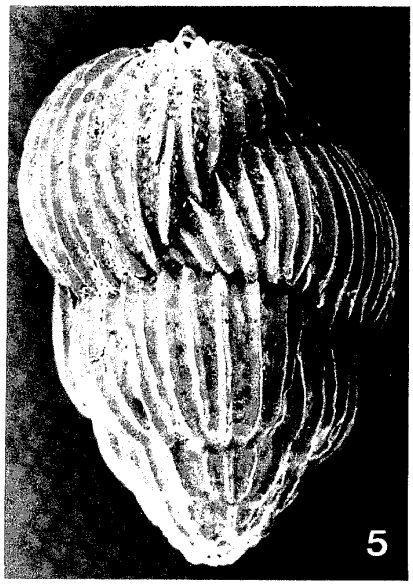
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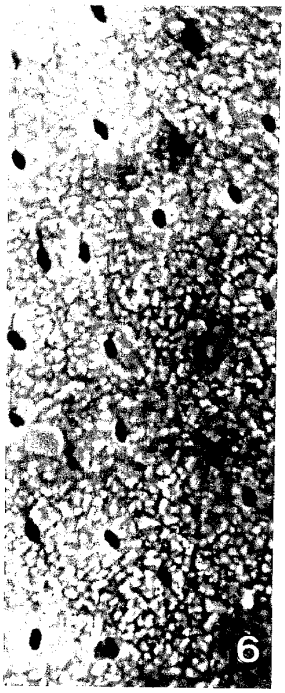
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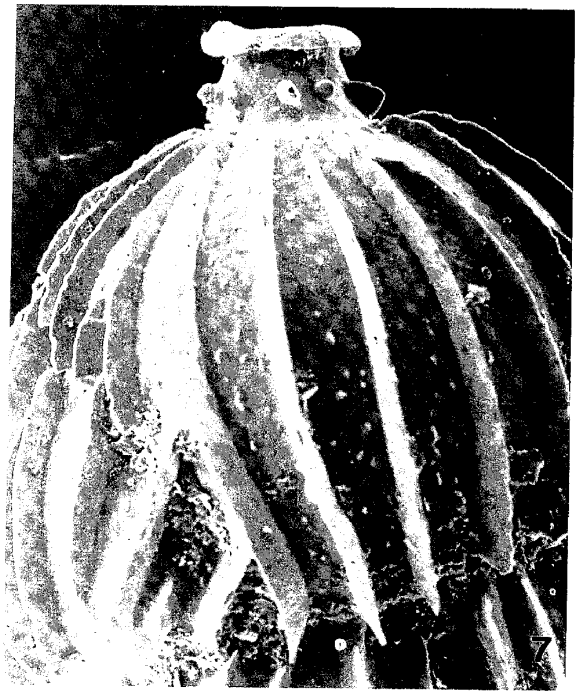
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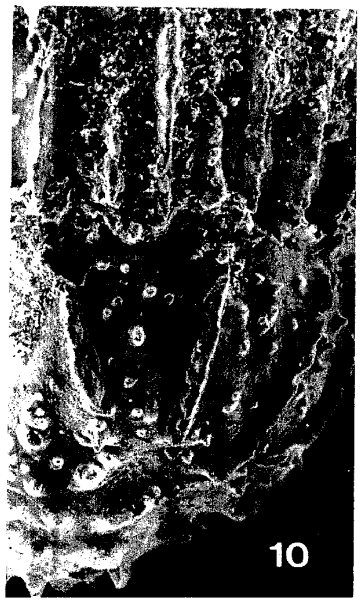
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Plate 46

(All figures are scanning electron micrographs)

Figs. 1–7. *Euuvigerina introrsa* Jung, n. sp.

1. Holotype, IGPS 99791 ; 2–5. Paratypes, IGPS 99792–99795.
1–2. Sample OM-13, Takanabe Member, Koyu Formation, Miyazaki Prefecture. ×80.
3–4. Sample OK-1, middle part of Yonabaru Formation, Okinawa. ×80.
5. Sample OK-19, Shinzato Formation, Okinawa. ×80.
6. Details of pores in penultimate chamber of Fig. 4. ×3,850.
7. Details of ornamentation of Fig. 3. ×250.

Figs. 8–11. *Euuvigerina hispidocostata* (Cushman and Todd)

8, 9. IGPS 99789, 99790. Sample OK-1, middle part of Yonabaru Formation, Okinawa. ×80.
10. Details of ornamentation of Fig. 8. ×250.
11. Details of pores in ultimate chamber of Fig. 9. ×3,850.

Plate 47

(All figures are scanning electron micrographs)

Figs. 1–9. *Euuvigerina hispida* (Schwager)

1, 3. IGPS 99783, 99785. Sample KT 85-6, G-2, water depth 938 m, Enshu-nada. ×80.

2. IGPS 99784. Sample KT 81-15, G-10, water depth 1,107 m, Kii-suido. ×80.

4. IGPS 99786. Sample TS-9, water depth 1,050 m, Tosa Bay. ×80.

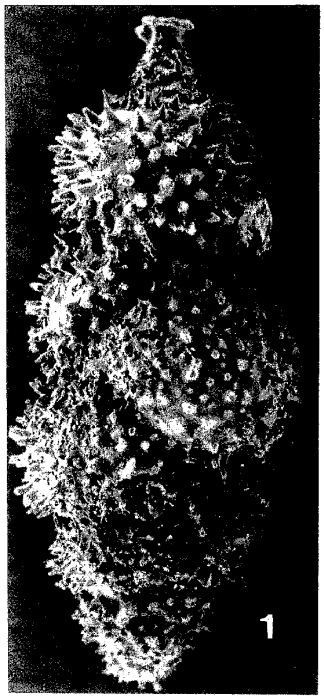
5. Details of ornamentation of Fig. 1. ×250.

6. Details of pores in penultimate chamber of uncatalogued specimen in the IGPS collection. ×3,850.

7. IGPS 99787. Sample OK-1, middle part of Yonabaru Formation, Okinawa. ×80.

8. IGPS 99788. Sample R684, middle part of Yonahama Formation, Miyako-jima. ×80.

9. Details of wall surface of Fig. 7, showing lamellar construction of spines. ×1,600.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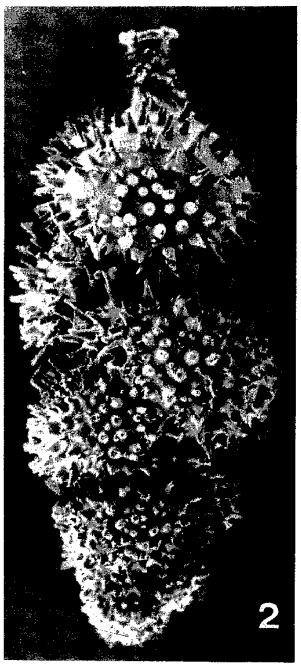
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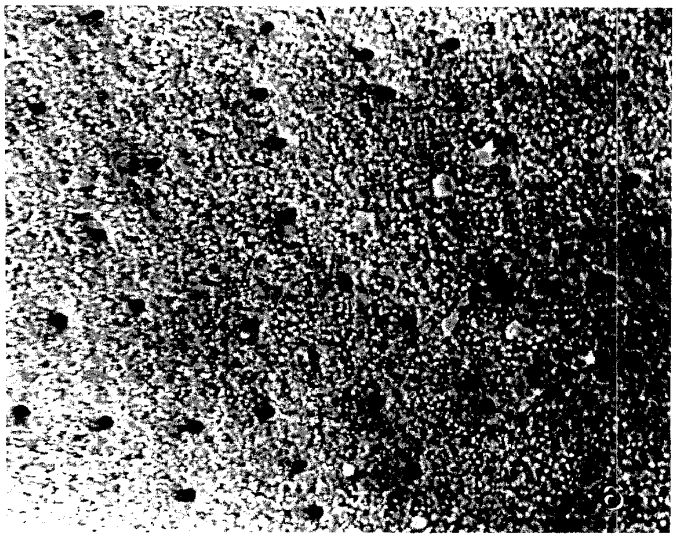

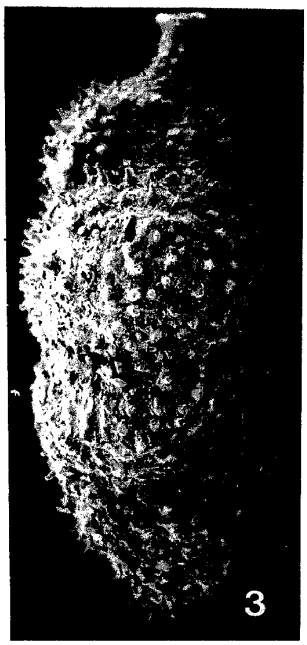
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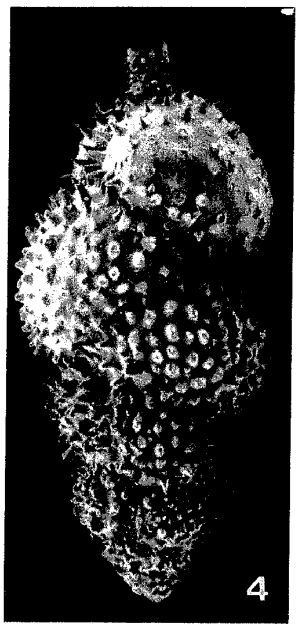
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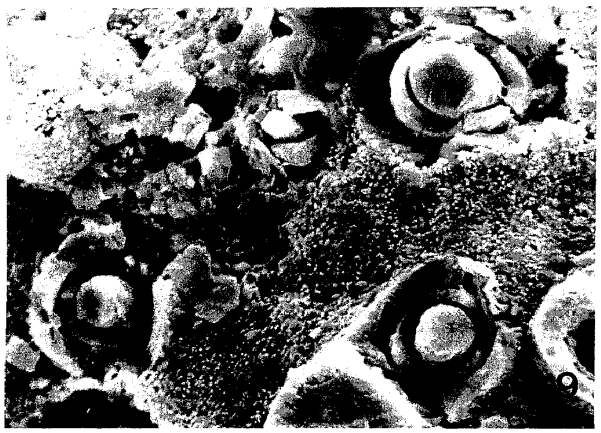
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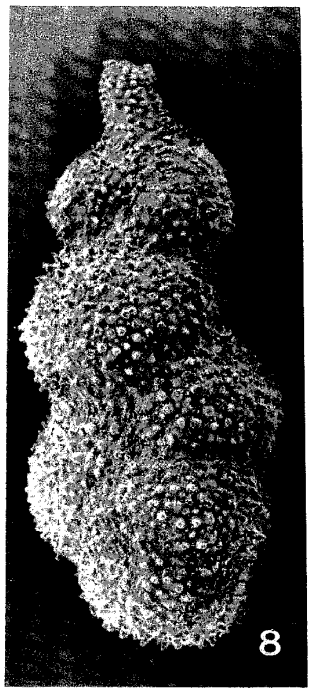
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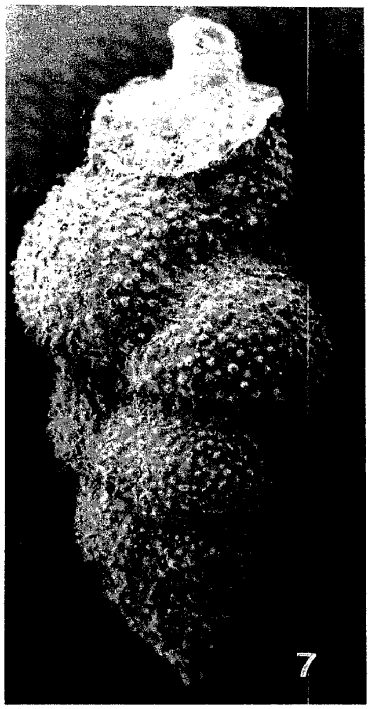
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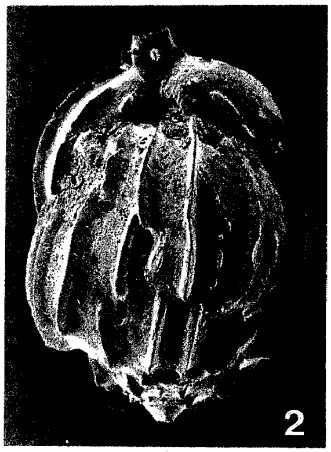
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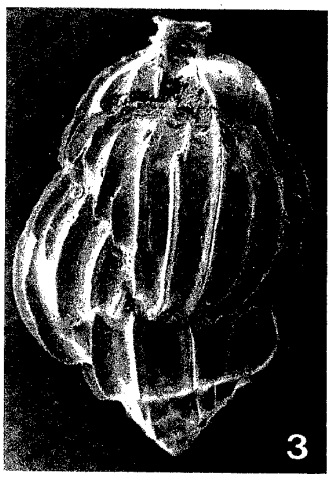
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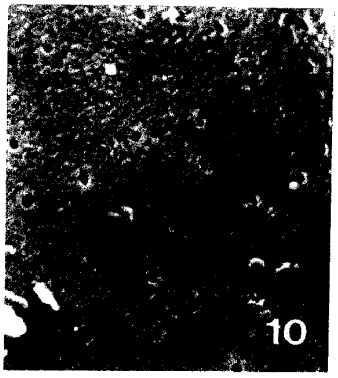
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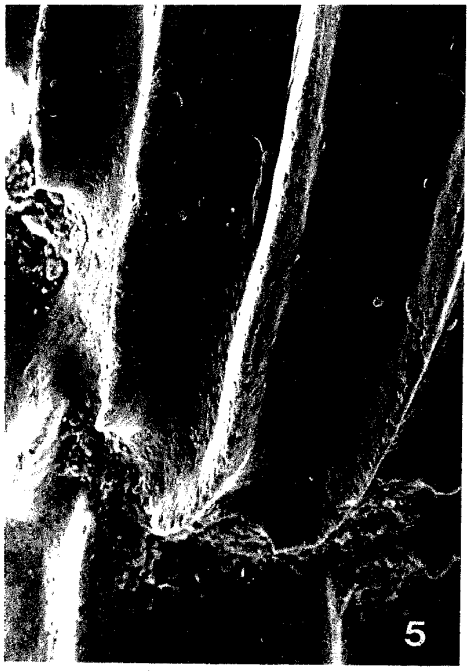
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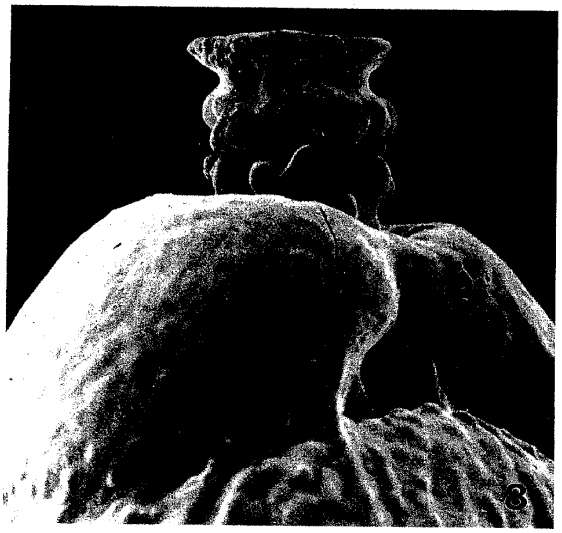
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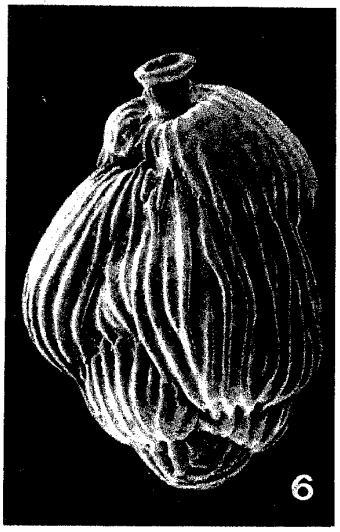
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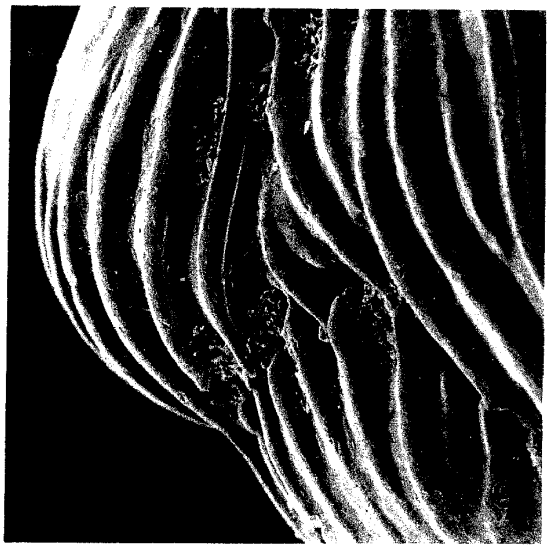

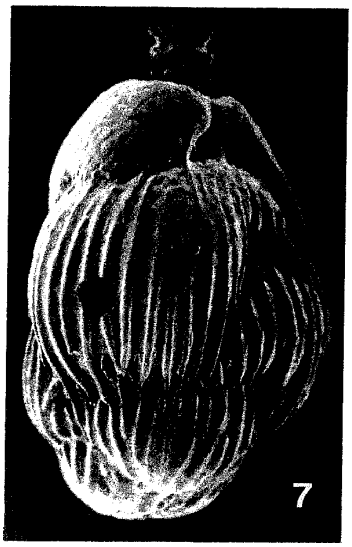
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Plate 48

(All figures are scanning electron micrographs)

Figs. 1-5. *Euuvigerina* sp. A

1-3. IGPS 99831-99833. Sample HE-4, Kawabaru Member, Saito Formation, Kawaminami-cho, Koyu-gun, Miyazaki Prefecture. 1. ×105 ; 2, 3. ×78.

4. Details of pores in penultimate chamber of Fig. 2. ×2,500.

5. Details of ornamentaion of Fig. 3. ×380.

Figs. 6-10. *Euuvigerina flintii* (Cushman)

6, 7. IGPS 99781, 99782. Sample OK-1, middle part of Yonabaru Formation, Okinawa. ×120.

8. Details of neck ornamentation of Fig. 7. ×380.

9. Details of ornamentation of Fig. 6. ×380.

10. Details of pores in ultimate chamber of Fig. 6. ×3,850.

Plate 49

(All figures are scanning electron micrographs)

Figs. 1–6. *Euuvigerina schwageri* (Brady)

1, 2. IGPS 99820, 99821. Sample R684, middle part of Yonahama Formation, Miyako-jima. 1. ×37; 2. ×57.

3. IGPS 99822. Sample KT 85-6, G-9, water depth 196 m, Enshu-nada. ×57.

4. IGPS 99823. Sample TS-7, water depth 918 m, Tosa Bay. ×57.

5. Details of wall surface in ultimate chamber of Fig. 4. ×1,600.

6. Details of depressed area around neck of Fig. 3. ×380.

Figs. 7–9. *Euuvigerina nanataniensis* (Matsunaga)

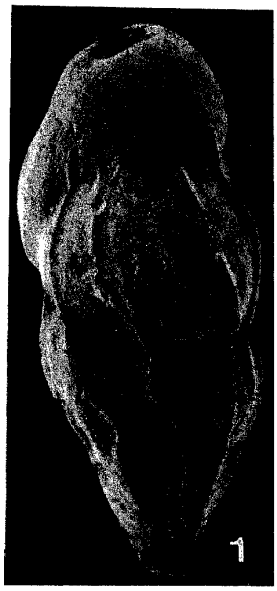
7, 8. IGPS 99810, 99811. Sample NA-3, Nanatani Formation, Minami-kanbara, Niigata Prefecture. ×80.

9. Details of depressed area around the neck of Fig. 7. ×250.

Figs. 10–12. *Euuvigerina* (*Hopkinsina*) *imogawaensis* (Matsunaga)

10, 11. IGPS 99834, 99835. Sample NA-5, Nanatani Formation, Minami-kanbara, Niigata Prefecture. ×57.

12. Details of ornamentation of Fig. 11. ×580.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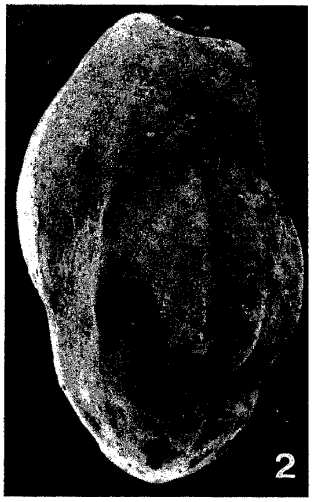
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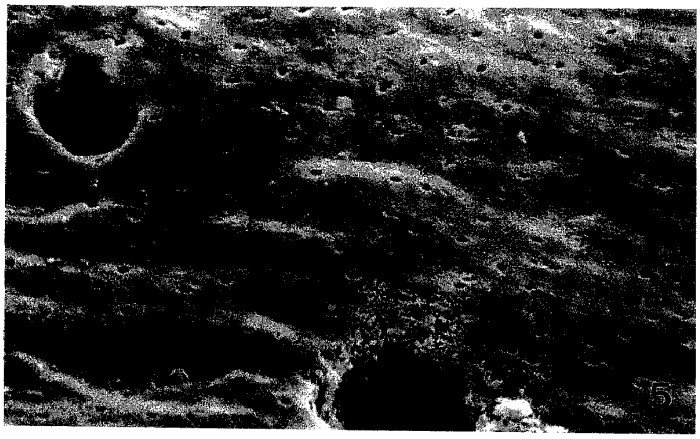
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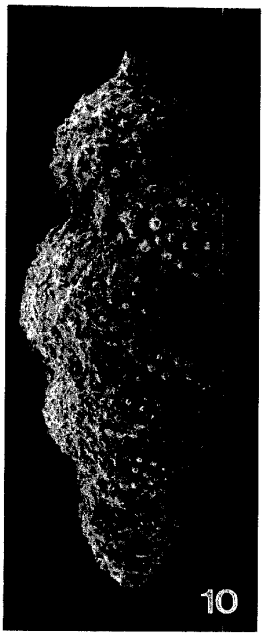
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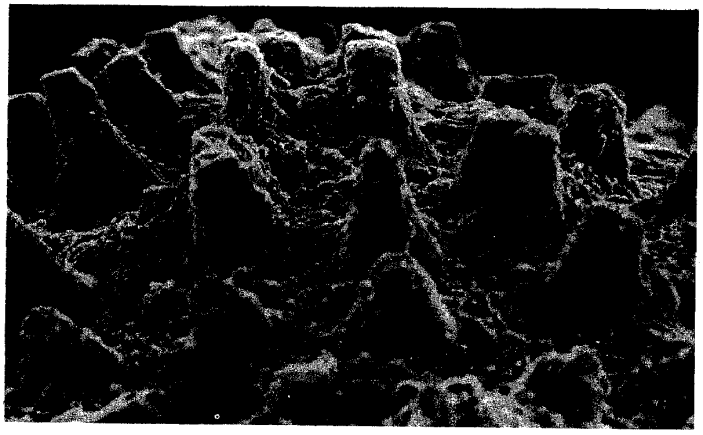

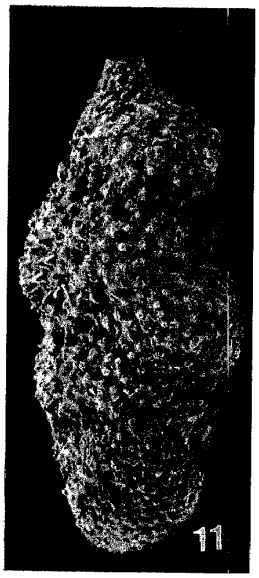
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